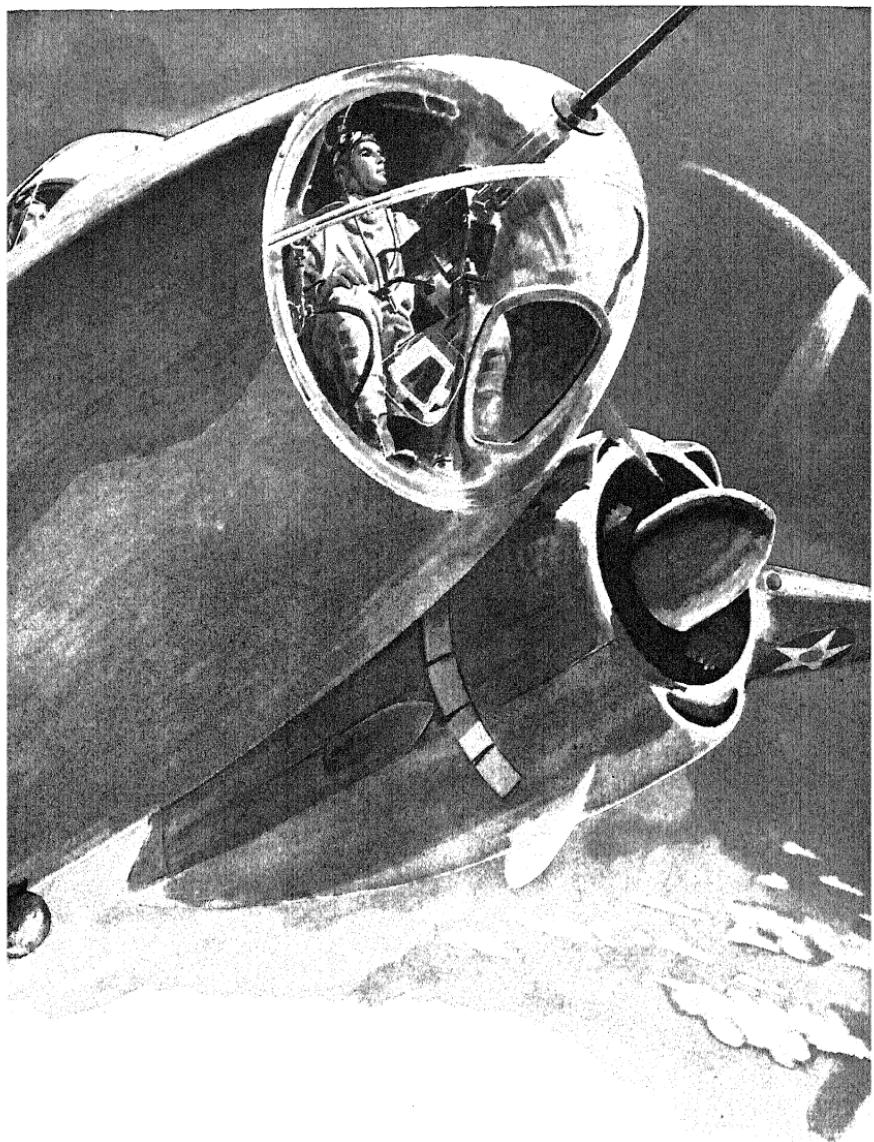


SCIENCE REMAKES OUR WORLD

JAMES
STOKLEY

SCIENCE
REMAKES
OUR WORLD



COMBAT FLYER'S PLASTIC "GREENHOUSE" . . . SHATTER-
PROOF, LIGHT IN WEIGHT, PERMANENTLY CLEAR
(see page 42)

SCIENCE REMAKES OUR WORLD

JAMES STOKLEY

Author of "Stars and Telescopes," etc.



IVES WASHBURN • PUBLISHER • NEW YORK

COPYRIGHT, 1942, BY JAMES STOKLEY

All Rights Reserved

*No part of this book may be reproduced in any form
without permission in writing from the publisher,
except by a reviewer who may quote brief
passages in a review to be printed in a
magazine or newspaper*

First Printing, November 1942

Second Printing, February 1943

PRINTED IN THE UNITED STATES OF AMERICA
BY THE VAIL-BALLOU PRESS, INC., BINGHAMTON, N. Y.

TO DOT

Acknowledgments

It is, I think, obvious that the preparation of a book covering as many branches of science as this requires information obtained from many sources. Technical books, papers in scientific journals, official releases from industries and from the meetings of various societies, private correspondence—to all these the author went for material.

Particularly do I wish to express my indebtedness to Laurence A. Hawkins, executive engineer of the General Electric Research Laboratory, for his help and suggestions, and to Joseph L. Smith and Helena A. Stalnacke, of Ives Washburn, Inc., for their skillful attention to the many technical details involved in bringing this book to completion. And among others who helped in many ways—for example, by furnishing data or by checking the text—I desire to thank the following: C. R. Addinall, Merck and Co.; Frank Benford, G. E. Research Laboratory; J. R. Brown, Jr., Esso Laboratories; Harold Burris-Meyer, Stevens Institute of Technology; Ernest E. Charlton, G. E. Research Laboratory; N. R. Chillingworth, Mine Safety Appliances Co.; Watson Davis, Science Service, Inc.; Saul Dushman, G. E. Research Laboratory; Gustav Egloff, Universal Oil Products Co.; Raymond M. Fuoss, G. E. Research Laboratory; James T. Grady, American Chemical Society and Columbia University; William A. Hamor, Mellon Institute; Hoyt C. Hottel, Massachusetts Institute of Technology; Ernest L. Little, National Farm Chemurgic Council; Vincent Lyons, Celanese Corporation; Don Masson, Bakelite Corporation; John Mills, Bell Telephone Laboratories; William H. Milton, Jr., G. E. Plastics Department; Frank J. Norton, G. E. Research Laboratory; G. Edward Pendray, Westinghouse Electric and Manufacturing Co.; Walter A. R. Pertuch, The Franklin Institute; Neil B. Reynolds, General Electric Co.; H. M. Richardson, G. E. Plastics Dept.; John J. Rowlands, Massachusetts Institute of Technology; M. L. Sandell, Eastman Kodak Co.; Waldo L. Semon, Hycar Chemical Co.; Igor I. Sikorsky, Vought-Sikorsky Aircraft; Burwell B. Smith, S. Morgan Smith Co.; Steven M. Spencer, E. I. du Pont de Nemours and Co.; Mary Stevenson, Columbia University; J. W. Stillman, E. I. du Pont de Nemours and Co.; Perry R. Stout, Massachusetts Institute of Technology; Herbert H. Uhlig, G. E. Research Laboratory; B. L.

Vosburgh, Schenectady, N. Y.; Robert R. Williams, Bell Telephone Laboratories; and Vladimir K. Zworykin, RCA Laboratories.

I also wish to express my appreciation to the following firms who furnished illustrative material: Bettmann Archive, photograph 2; W. Atlee Burpee Co., photograph 32; Celanese Corporation of America, jacket illustration of Celanese; Celluloid Corporation, jacket illustration of Lumarith; Dow Chemical Company, jacket illustration of Dowmetal; E. I. du Pont de Nemours & Company, photograph 4 and jacket illustrations of rayon thread, Exton, Lucite and Nylon; Eastman Kodak Co., photograph 28; General Electric Co., photographs 8, 9, 11, 13, 14, 15, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 29 and 35; Hanovia Chemical and Manufacturing Co., photograph 7; J. B. Lippincott Company, diagram on page 99, from their publication, "Nutrition in Health and Disease," by Cooper, Barber, Mitchell; Merck and Co., photograph 2; Mine Safety Appliances Co., photograph 3; Modern Plastics Magazine, jacket illustration of Texolite; Monsanto Chemical Company, photograph 4; Owens-Corning Fiberglas Corporation, photograph 10 and jacket illustration of Exterminator Ray; R.C.A. Research Laboratories, photograph 19; Shell Oil Company, Inc., photograph 1, *copyright by Shell Oil Co., Inc.*; S. Morgan Smith Co., photograph 34; Standard Oil Company of New Jersey, photographs 5 and 6; Tennessee Eastman Corporation, jacket illustration of Tenite; University of California, photographs 31 and 33; Vought-Sikorsky Aircraft, photograph 12; Westinghouse Electric and Manufacturing Co., photographs 16, 30, and jacket illustration of Atom Smasher.

Contents

I.	<i>New Frontiers</i>	1
II.	<i>Explosives in Peace and War</i>	12
III.	<i>Fuel for Tomorrow</i>	24
IV.	<i>The Realm of Plastics</i>	35
V.	<i>Chemical Clothes</i>	48
VI.	<i>Rubber from Tree and Test Tube</i>	59
VII.	<i>Chemistry and the Farmer</i>	70
VIII.	<i>Chemicals for Cures</i>	85
IX.	<i>Vitamins</i>	92
X.	<i>New Metals</i>	111
XI.	<i>Mining the Ocean</i>	129
XII.	<i>The Magic of Glass</i>	136
XIII.	<i>Higher, Faster, Farther . . .</i>	155
XIV.	<i>The Age of Electrons</i>	168
XV.	<i>Radio Today and Tomorrow</i>	187
XVI.	<i>Light and Light Sources</i>	210
XVII.	<i>Pictures of the Future</i>	226
XVIII.	<i>New Sounds in the Theater</i>	244
XIX.	<i>Into the Atom</i>	255
XX.	<i>New Sources of Power</i>	267
	Appendix: <i>Rubber and Its Relatives</i>	285
	Index	289

Illustrations

1. Combat flyer's plastic "greenhouse" . . . shatter-proof, light in weight, permanently clear	Frontispiece	Facing page
2. From the work of ancient alchemists comes modern chemistry	16	
3. Cable splicer powered by explosive, in use by a lineman	17	
4. Plastics come in many forms and colors—some beautifully transparent	32	
5. A stage in processing butyl rubber from petroleum-refinery gases	33	
6. Oxygen soon cracks a tube of natural rubber, but one of butyl rubber is not affected	33	
		Between pages 112-113
7. Typical installation of Vitamin D milk irradiators	"	
8. Magnets to hold dentures in place	"	
9. Tiny magnet supports girl	"	
10. Glass is made into a fiber from which are spun beautiful fabrics	"	
11. Glass is made non-reflecting in this great sphere	"	
12. Like a humming bird, Igor Sikorsky hovers in his helicopter	"	
13. To make planes fly higher—turbosupercharger parts	"	
14. 1,400,000-volt X-ray machine	"	

15. *With million-volt X-rays men look through steel castings* " " " "

16. *High-speed radiograph of a football being kicked* Between pages 192-193 " "

17. *Studying plastic replicas of snowflakes showed how to view metals in electron microscope* " "

18. *Model of a crystal as revealed by the electron camera* " "

19. *The electron microscope extends man's range of vision* " "

20. *Carbon steel magnified 2000 times with light microscope and 28,000 times with electron microscope* " "

21. *How FM reduces static to the vanishing point* " "

22. *Television Studio WRGB* " "

23. *Ice melts in a jar of water* " "

24. *High-intensity mercury lamp tests flaws in glass* " "

25. *Fluorescence makes airplane instruments visible at night* " "

Between pages 256-257 " "

26. *Power from sunlight* " "

27. *Chemical light* " "

28. *Stroboscope photograph of a falling glass of water* " "

29. *Huge test tube for separating isotopes* " "

30. *Inside a Van de Graaff generator* " "

31. *Cyclotron under construction* " "

32. *New variety of calendula produced by X-rays* " "

33. *Radiophosphorus as tracer element in tomato* " "

34. *Power from wind on Grandpa's Knob* " "

35. *20,000,000-volt electron whirlpool* " "

SCIENCE
REMAKES
OUR WORLD

I. *New Frontiers*

Today's most promising frontiers are those of science—those which are being explored by research workers in laboratories both great and small. They have largely replaced the geographical frontiers of the past. And these new frontiers have a great advantage over the older ones. After all, space on the earth's land masses is limited, but the scope of exploration in science is infinite. Whenever science, in the past, has seemed to reach a dead end, a new road has opened, generally far broader than that left behind. There is every reason to think that this will continue indefinitely—that we shall never reach a state where knowledge will be complete.

Although its roots extend back into past centuries, present-day research is mainly a development of the last fifty years. Before that time there were isolated workers, or at most small groups, mainly in college and university laboratories. They made great and important contributions—as, for example, when Joseph Henry in the United States and Michael Faraday in England independently discovered the principles upon which all generation of electricity now depends. Until about the beginning of the twentieth century, however, there was little or no effort to co-ordinate industry with research—to make the results of the laboratory available for some practical use. The discoveries of Faraday and Henry were made as far back as 1831, but it was a full half-century later before humming dynamos began to produce the first electricity for lighting our cities.

Now the situation is far different. Great laboratories are operated by industries, so that the scientist and the man in industry are closely in contact: each can appreciate the work of the other. This association of industry and research has not lessened the

2 SCIENCE REMAKES OUR WORLD

quality of the latter—it has in fact improved it. Merely to spend large sums of money does not guarantee scientific discoveries; the man himself is still the most important factor; but even a good man can do still better with adequate technical equipment. This sometimes is so expensive that only a large corporation can afford to invest in it. Equipment for creating artificial lightning is an instance. It is difficult to imagine that any college or university would have spent what it costs to produce lightning of 10,000,000 volts. Yet the equipment has been made and put to such good use that lightning, now that it has been studied under controlled conditions, no longer offers the hazards to the transmission of electrical power that it did a few years ago. With increased reliability of transmission it has become possible to use larger and larger generating units, such as those at Grand Coulee Dam, or at Muscle Shoals.

It might be supposed that research by industry would not be concerned with fundamentals; that emphasis would be centered on investigations showing some immediate likelihood of profits. However, in firms with the most enlightened research policies this is not the case; for it is realized that fundamental knowledge obtained today may lead to entirely unforeseen applications tomorrow. There is the oft-told story of Faraday, who was asked by Gladstone what use his discovery of electromagnetic induction would have. In reply, the scientist asked the statesman: "What use is a baby?" That particular baby grew up into the electrical industry of the present time—and it is still growing.

In addition to what the corporations are doing there is the great amount of important research being carried on by the Federal Government; at the National Bureau of Standards, for example, or in the Department of Agriculture and the Coast and Geodetic Survey. Also, many of the universities now co-operate with industry, perhaps making use of the fellowship system inaugurated by Robert Kennedy Duncan, first director of the justly famed Mellon Institute at Pittsburgh. Under that system it is possible for a firm of relatively small size, which could at the best set up a laboratory for only two or three men, to establish

a fellowship at a central research institution. The fellow, supported by the business organization, has the advantage of association with other scientists, and of the use of superior equipment which includes not only the laboratories but also the library and machine shop. The findings of the fellow are at the disposal of the donor; and even many large companies which maintain full research staffs of their own have taken advantage of facilities such as those afforded at the Mellon Institute.¹

In the following pages we shall see several instances of industrial research into fundamental principles, performed without any direct thought of application for profit. Yet applications appeared when the knowledge was obtained. Thus, when Dr. Kenneth D. Hickman studied the problems of distillation in a high vacuum, his findings led to the discovery of a means of carrying on the commercial distillation of vitamins from fish oils. This was far removed from the interests of the photographic concern for which Hickman worked, so a subsidiary company was established to utilize his process in fish-oil distillation. In the laboratory of another corporation Dr. Irving Langmuir worked for years on gases which seemed to come out of hot filaments, until his conscience troubled him about spending so much time on a task which showed so little promise of results. Yet directly from Langmuir's work came modern incandescent lamps which, compared to their predecessors, operate at a saving of millions of dollars nightly. And for several years Wallace H. Carothers studied the behavior of long chain-like molecules, seeking merely to learn all he could about them. Yet from Carother's research comes nylon and a whole family of related fabrics superior to silk, which they are replacing in the manufacture of gunpowder bags and parachutes, as

¹ By far the most complete summary of industrial research is the 370-page report prepared by a special committee of the National Research Council, and issued in 1941 by the National Resources Planning Board. This showed, as of 1940, that 2350 companies in the United States operated a total of 3480 laboratories, employing 70,033 persons. More than half of this number are professionally trained. Chemists are most numerous, with 22.4 per cent of the total, but engineers run a close second with 21.4 per cent.

4 SCIENCE REMAKES OUR WORLD

surgical sutures, and for the stringing of pearls and tennis rackets.

At war or at peace, then, our world of today is a very different place from what it was a few generations ago. Thanks to scientific research new jobs, new processes and new industries have come into being. No matter how isolated he may be, no one alive today has been wholly immune to their influences. The complete story of these studies and their results is told in countless reports to technical societies, in patents, in scientific books and journals. But this mass of material, though it is available in the nation's libraries, is hardly in a form convenient for consultation by most of us whose lives it has affected so greatly.

In this book it is the author's aim to tell the story of a few of the more important scientific developments of our day. Obviously it will be necessary to omit much that might have been included; but it is hoped that these chapters will give the reader some idea of typical ways by which, in its many branches, science is remaking our world. Physicists, chemists, biologists, psychologists, men and women in all branches of science have taken part, though perhaps the best-known scientific discoverers of the past few years have been concerned with chemistry. So, before we start on our explorations, let us get acquainted with some of the chemist's tools.

Fundamentally, the work of the chemist is to rearrange atoms. Of course atoms can be rearranged without his services —they were, long before the chemist appeared. When anything burns, atoms are moved about. And life, even the most primitive, is itself made possible only because of the atomic shifts that occur in living cells.

When the sun's rays fall on water in ocean or lake and evaporate it, no rearrangement of atoms happens in the process. The vapor is carried in the air over land, where it may be cooled and fall as rain, going into rivers, perhaps dropping over waterfalls

on the way back to the ocean; but the molecules, the units of which water is made, consist of building blocks still smaller—the atoms, of which nature has 92 separate kinds. A water molecule contains three such atoms. Two of them are alike; they are hydrogen atoms, while the third is oxygen. To indicate this, the chemist calls water H_2O . No matter whether water is in liquid form as in lake or ocean, or in vapor form as in the atmosphere, it still consists of these same three atoms.

But the chemist can perform an experiment with water in which electricity pulls the hydrogen and oxygen atoms apart. If two pieces of metal are connected to a source of electricity and immersed in a jar of water as it comes from the tap, bubbles soon begin to appear around them. The bubbles may be collected separately, and we then have two gases which are quite different—one will burn, the other will not. The former is hydrogen, the latter is oxygen. With one of the chemist's most useful tools has been performed the seemingly magical experiment of converting a liquid into two different gases. If we wish, we can collect hydrogen and oxygen from this process, which is called electrolysis, and recombine them. Electricity can again cause the joining, for an electric spark, inside a glass tube containing the two gases, will make them explode, and inside the tube small drops of water will appear.

Also heat, as from a match flame, might initiate the recombination. And indeed heat, in the form of fire, is the oldest of the chemist's agents and is still his most important one. That is why every laboratory table has on it a Bunsen burner—a type of gas burner, similar in principle to the one in your gas range, which burns the gas without making smoke. Incidentally, it burns without much light either, for the illumination which the old-style open gas flame gave resulted from the heating, by the flame, of the smoke particles caused by incomplete burning. Illuminants were put into the gas to increase the number of these glowing particles.

Chemical changes are, in general, speeded by heat, and that is why heat is important to the chemist. The speed of a chemical

6 SCIENCE REMAKES OUR WORLD

reaction is approximately doubled for every increase in temperature of 18 degrees Fahrenheit. This speeding up is responsible for the mysterious fires caused by "spontaneous combustion." A big pile of coal, of oily rags, or even of hay, may thus take fire. Burning of any kind is simply the joining of atoms with oxygen; and oxygen usually comes from the air, of which it forms about a fifth part. Even at ordinary temperatures the joining of oxygen atoms liberates a small amount of heat, so our pile of oily rags tends to get a little warmer. Especially if the pile is a large one, and not ventilated, the warm air accumulates. Then, as it gets hotter, the reaction is accelerated, and as it accelerates there is still more heat given off. So the temperature may gradually work up until it reaches the combustion point and the pile begins to blaze. Fire, or combustion, is merely a very rapid form of oxidation, with the liberation of light and heat.

The temperature of a flame is less or more intense, depending on what is burning. The hottest, that of oxygen and acetylene in a special torch used for cutting through metal, reaches 5500° Fahrenheit. At the other extreme is the flame of cotton soaked in a mixture, in correct proportions, of carbon disulfide and carbon tetrachloride. This makes a flame well below the boiling temperature of water; in fact, it is possible to hold the burning mass in the hands without discomfort.

As a simple example of the use of heat in aiding a chemical reaction, we might take the way the French chemist Lavoisier first separated oxygen from the air. For many days he heated some mercury (quicksilver) in a retort in which air was present, and finally a red powder appeared on the shiny surface of the liquid metal. This was mercuric oxide, made up of molecules in which mercury and oxygen atoms combined. But when the red mercuric oxide was heated to temperatures much higher than those he had used at first, it changed back to mercury, and oxygen was given off. Indeed, it was by heating the red oxide with the sun's rays concentrated by a huge burning lens that the English clergyman and chemist, Joseph Priestley, had discovered oxygen in the first place. Nowadays, however,

chemists have much more convenient sources of heat for speeding their reactions. If the gas flame of the Bunsen burner is not hot enough, hotter flames are used, or else the electric arc, which gives controllable temperatures of many thousands of degrees Fahrenheit.

In most chemistry courses today, one of the first laboratory experiments is the preparation of oxygen; but Priestley's method is not used. Instead, a mixture of potassium chlorate and manganese dioxide is put in a test tube and heated. Oxygen results. Potassium is a soft, white, silvery metal and, in the chlorate, its atoms are combined with those of the gases chlorine and oxygen. Manganese is a heavy, grayish metal, and is compounded with oxygen to form the dioxide.

After one has obtained all the oxygen possible from heating a mixture of these compounds, an examination and analysis of the material remaining in the test tube would reveal there the presence of potassium chloride, for one thing. This is simply a combination of potassium and chlorine—the oxygen that was present in the chlorate having been given off as gas. But what about the manganese dioxide? Surprisingly enough, that is still present, after the reaction, and unchanged. But if, thinking the manganese dioxide unnecessary, you tried to make oxygen merely by heating potassium chlorate, you would have a hard time getting any.

The manganese dioxide plays the part of a catalyst, which is perhaps the most "magical" of all the aids employed by the chemist. A catalyst is a substance which speeds (or, sometimes, retards) a chemical reaction, but which in the end remains in its original form. Various analogies have been used to describe such substances. They have been called "chemical Parsons" for, like the clergyman performing a wedding ceremony, they "marry" atoms. Another analogy has been used by Dr. Roger J. Williams, of the University of Texas. Pointing out that chemists often express in simple form what happens in a chemical change by writing the first substance, then an arrow, then the second substance, he said that the catalyst "lubricates the arrow."

In a great number of chemical processes used in industry, catalysis plays a vital part; and catalytic agents will often be mentioned in later chapters. Most sulfuric acid today, for example, is made by the "contact process." Sulfur dioxide, which can be made by burning sulfur, is mixed with air, then passed through tubes containing a catalyst, such as finely divided platinum or ferric oxide, which makes the dioxide into sulfur trioxide by adding atoms of oxygen from the air. The trioxide dissolves in water to form sulfuric acid. In making ammonia by the Haber process, as we shall see later, finely divided iron is the catalyst which makes nitrogen combine with hydrogen. Nickel is the catalyst used in commercial "hydrogenation" processes to make liquid fats react to form solid fats. Hydrogenation has also been applied in the Bergius process to make petroleum and its products, such as gasoline, from coal and hydrogen. This is the German development which provided much of the fuel needed for Hitler's mechanized warfare.

Just what a catalyst does is still a problem, and much chemical research has been expended in hunting for an answer. There are really two kinds of catalysis. In one there is a reaction of the catalyst with one of the original compounds; and this in turn reacts with the second. In this final change, the catalyst itself is regenerated. Such a process takes place throughout the mixture; and in general, the more catalyzer there is, the faster the reaction goes.

The other kind is surface catalysis, and makes use of a solid divided into very fine particles so as to give a great deal of surface. Finely divided platinum, vanadium, nickel or very porous charcoal are among those often used. This time the raw materials of the process, such as the sulfur dioxide and the oxygen in the contact process of making sulfuric acid, link themselves to the platinum atoms on the surface of the particles; and in this state they can unite with each other, whereas out in the open they could not. Here, again, an intermediate compound is formed, but it is in a layer, only one molecule deep, on the surface of the catalyst. This is why the surface has to be as

large as possible. Not only is the catalyst finely divided, but also fine cracks in the particles, perhaps too small to be seen even with the microscope, increase it still further.

Catalysts, like animals, may be poisoned, and with some of the same poisons, too. Arsenic, for example, even if present in minute traces, will make the platinum catalyst inactive. It seems to do this by taking hold of the loose electrons in the surface of the platinum and joining with them to form a layer of a compound of platinum and arsenic. As this layer is only one molecule deep, a very small amount of arsenic will cause such poisoning; there are then no loose electron handles for the sulfur dioxide or other molecules to grab. But the catalytic action of platinum, after arsenic has destroyed it, can be restored by treating it with strong nitric acid.

The efficacy of platinum in this spongy condition in accelerating reactions is shown by the way it makes hydrogen and oxygen unite to form water. In fact, if you have a mixture of the two gases and toss in a bit of spongy platinum, the gases come together with a loud explosion. Such material also causes the ignition of coal gas in air. In this form it has been used for a gas lighter, and also in a cigarette lighter, where it ignites alcohol vapor.

Of particular importance to our life processes are catalysts of the class called enzymes, formed in living cells. Without them, cells could not carry out the chemical reactions of their life processes at the proper speed unless the temperature was much higher. Enzymes are responsible for the changes that take place in digestion. This starts in the mouth. In saliva there is an enzyme called ptyalin, which has the function of converting starch in the food into a sugar. This is not ordinary sugar but another member of the same class of carbohydrates, called maltose. In the small intestine another enzyme, maltase, converts the maltose into glucose, which the body absorbs through the intestinal wall. Other kinds of foods are digested, thanks

to other enzymes; and even such biological processes as reproduction and heredity, it has been suggested, are caused by the action of these catalysts.

Industrially, the enzymes are used under controlled conditions—the oldest of such applications, perhaps, being in the baking of bread and the brewing of beer. In beer brewing, the first change is very similar to what happens to the starches in the mouth. The barley contains starch, and before use it is allowed to germinate. This produces the enzyme diastase, which, like ptyalin, converts starch into maltose, and also into malto-dextrin and dextrin. These, in turn, are acted on by zymase, which is present in yeast; and alcohol is the product. This occurs, as it does in many of the processes in which the enzymes play a part, by hydrolysis—the union of water with the original material. Usually, in brewing, conversion to alcohol is not fully carried to completion, and some sugars remain. The longer the process continues, in general, the less sweet the beer will be.

The process by which meat becomes tender as it is stored is also carried on by enzymes. This "tenderizing" can be hastened by the use of papain, which is present in pineapples and is also obtained from the papaya. Another group of enzymes is responsible for the blackening of an apple or potato when cut and exposed to the air. Then the reaction involves union with oxygen instead of water.

A striking feature of the work of enzymes is the exceedingly minute amount needed to accomplish the result. For instance, invertase, which converts ordinary sugar into two others, fructose and glucose, is so potent that it will initiate the change in a million times its own weight of sugar.

One might list many more items among the so-called "magic wands" of the chemist. Seemingly magical in their action, to the layman, are such agents as the indicators, which tell by a change in color how acidic or alkaline a mixture is, and which

play an important part in much of the chemist's work. Then too there is the process of "fractionation," by which molecules can be sorted out, even though they are not changed in the process. This has to do with the different boiling points of substances which may be mixed, as are the various compounds of hydrogen and carbon in the oil that pours out of oil wells. The first separation of gasoline is done by such fractionation. After that, using catalysis and other methods, the other fractions, with both higher and lower boiling points, can likewise be converted into gasoline, a process to be described in detail in a later chapter.

But, magical as these chemical agents and processes may appear, that word can hardly be applied to them. Chemistry was once mixed up with magic. That, however, was in the days when chemists were still called alchemists and sought, by spells and incantations, for the philosopher's stone which, so they thought, would in a minute quantity change lead into gold. The alchemists never succeeded, but they did acquire much information which laid the foundation upon which the real science of chemistry arose after spells were banished from the laboratory.

Surely the wonders that can be accomplished with catalysts and enzymes are even more marvelous (and of considerably more practical value) than what the philosopher's stone might have done. Yet the curious thing is that, without magic, the ancient dream of the alchemists has been realized: even the transmutation of one element into another—into gold—has been accomplished in the newest kind of chemistry. This kind goes beyond the atom, into its very nucleus, and there, with powerful atom-smashers, produces fundamental changes. However, before we hear about that, let us see some of the achievements of the older kind of chemistry, which still is turning out gasoline, foods, explosives, rubber and all the other products vital to our civilization, whether at war or in peace.

II. *Explosives in Peace and War*

When we think of explosives, most of us think of war—of the bombs, shells, cartridges and other carriers of substances that go “bang.” Yet the two billion pounds of explosives expended by the Allies during World War I did not exceed the amount that the United States used in a like length of time, from 1936 to 1940, for pacific purposes. In other chapters we shall see how the petroleum, mining and metal industries have made our civilization possible. But those industries could not have reached their present position, where they are indispensable to our national existence, without the help of explosives.

Alfred Nobel invented dynamite in 1867. When it was applied to the mining of copper, for example, the production of that metal proceeded with enormous acceleration, thus keeping up with demands for copper from a rapidly growing electrical industry. In recent years, under normal conditions, our annual use of explosives in the United States has been between 300,000,000 and 500,000,000 pounds, of which about a third is expended in coal mining, a fifth in mining other ores, a sixth in quarrying rock and the rest in clearing stumps from land, building roads and tunnels, and opening ice jams in rivers.

Practically all explosives that are commonly used contain nitrogen and, in preparing them, nitric acid is employed to introduce this important element. In earlier days the acid was made from deposits of saltpeter—that is, potassium or sodium nitrate. Natural saltpeter deposits were too limited, however, to meet the demand for an indefinite time. So men looked longingly into the atmosphere, of which about four-fifths consists of nitrogen, with some 20,000,000 tons of the gas above every square mile of the earth’s surface.

When lightning flashes, the electrical discharge causes some

of this nitrogen to combine with a portion of the oxygen which forms the other fifth of the air. Nitric oxide is the result. As this cools, more atoms of oxygen are extracted from the air, and the result is nitrogen dioxide, a reddish-brown gas in concentrated form. This gas (NO_2 , as the chemist writes it, to show that two oxygen atoms are combined with one of nitrogen) readily combines with water, H_2O , made of hydrogen and oxygen, to form HNO_3 , or nitric acid. Since lightning usually occurs in connection with rain, this process takes place in every thunderstorm, and much of the rainfall in such a storm is actually very dilute nitric acid. A great deal of the nitrogen required for natural plant growth becomes fixated in this way. According to one estimate it amounts annually to 1,500,000,000 tons of nitrogen.

In 1903 the process was imitated by man, when two Norwegian chemists, Kristian Birkeland and Sam Eyde, prepared nitric oxide, and from it nitric acid, with an electric arc spread out into a disc six feet in diameter. This was the first successful process for the fixation of atmospheric nitrogen and was quite widely used, especially in Norway and other countries where abundant water power made electricity cheap. Since then, however, processes not requiring such a large amount of electrical energy have largely replaced the Birkeland-Eyde process, even in Norway. Today the process most widely used is one developed during World War I, when Germany's supply of salt-peter from Chile was cut off and nitrogen was needed for war explosives. Fritz Haber was the chemist mainly responsible. It is also known as the "synthetic ammonia" process, since ammonia makes possible one of the main steps.

Nitrogen boils at -195° Centigrade, and oxygen at -183° Centigrade. Thus, when air is liquefied, nitrogen boils off first and liquid oxygen remains. This convenient means of separating the gases in their pure form from the atmosphere is used to secure nitrogen for the Haber process. Hydrogen is obtained from water by the action of an electrical current. Then the hydrogen and nitrogen are forced, under pressures two hundred times that of the atmosphere, into huge cannonlike steel cylin-

ders, where the temperature is 500° Centigrade. Under these conditions, and with the aid of our friend the catalyst in the form of porous iron, many of the nitrogen atoms unite with three hydrogens to form NH_3 , which is ammonia. This is familiar to everyone in the form of ammonia water, used in the household. At a temperature of 600° Centigrade—again in the presence of a catalyst, platinum this time—ammonia will combine with oxygen from the air to form nitric oxide, and this is the second step in the Haber process. Then, as with other methods, the nitric oxide combines with more oxygen to form nitrogen dioxide and that, with water, to form nitric acid.¹

Though nitrogen goes into most explosives, other elements are needed too; and the demands of war require explosives of many kinds. Even a single shot from a 14-inch coast-defense gun uses several. The kick to drive the projectile on its way comes from hundreds of pounds of smokeless powder. In the projectile itself there may be a bursting charge of a few hundred pounds of high explosive. Perhaps there is a time fuse, to make it burst after a certain interval, and this will consist of a few pounds of old-fashioned black powder. But usually the shell explodes when it hits—then there is a detonator, of mercury fulminate. And to set off the high explosive there will be a booster charge of another explosive even more powerful.

The bursting charge is an explosive that goes off with great rapidity, building up its full pressure at once. This shatters the shell into fragments, which produce a maximum amount of damage. But if such an explosive were used in the gun barrel, the gun likewise would burst—with disastrous results. Smokeless powder, used for the propelling charge, goes off more gradually. It does not really explode but undergoes extremely rapid burning. Expanding gases in the barrel cause a more gradual building up of pressure behind the shell, accelerating it from rest, at the start, to its full speed at the mouth.

¹ This method has been used to produce enormous quantities of nitric acid, to supply our war needs, by the Du Pont Company, by the Allied Chemical and Dye Corporation and others.

The first propelling explosive was gunpowder, a mixture of powdered charcoal, sulfur and potassium nitrate (saltpeter). Roger Bacon, the Franciscan friar, is supposed to have made it in 1264. According to tradition a German monk, Berthold Schwarz, first used it in a cannon—to hurl stones. As early as 1340 there was a powder factory in Augsburg, Germany. At the battle of Crécy, in 1346, gunpowder and wooden cannon helped Edward III of England defeat Philip of France. And much earlier than any of these dates, in the ninth century, the Chinese are believed to have had gunpowder—which they used in fireworks. Apparently they never thought of using it to kill people!

Black powder, the modern form of gunpowder, is a burning explosive. Ignited by heat, as from a flame, the nitrate furnishes oxygen to supplement that of the air. The charge burns with great rapidity, the gases being generated as burning progresses. In any explosive these heated gases, many times the volume of the original solid or liquid, produce the effects desired.

By mixing glycerine, used in soap-making, with nitric and sulfuric acid, nitroglycerine is produced, as Ascanio Sobrero, an Italian, discovered in 1846. The chief use of the material, until Nobel introduced dynamite, was in medicine as a heart stimulant. A slight shock will explode nitroglycerine, but Nobel's great contribution was to mix it with an absorbent material; it can then be transported and handled. Originally an inert material called kieselguhr—a form of earth composed of the skeletons of minute organisms—was used, but this has been superseded by other materials. Sometimes, too, the nitroglycerine is mixed with gelatin to form blasting gelatin, an explosive widely employed in construction work. These explosives are set off by a detonator, such as mercury fulminate.

Born at about the same time as nitroglycerine was nitrocellulose, or guncotton, made by treating cotton with nitric acid. This was most temperamental, as the Austrians who

started making it in 1845 found when they blew up more of their own factories than they did of the enemy's works. Mixed with nitroglycerine, vaseline and acetone, however, nitrocellulose is made into smokeless powder, which is more tractable.

Actually "smokeless powder" does make some smoke—and it is not a powder. Flakes, strips, cylinders or pellets are the most usual forms. Cotton is the usual raw material, though any form of cellulose will do. In early World War I days, the British thoughtlessly allowed Germany to import cotton, apparently not realizing what it would be used for. When they did wake up, and the cotton supply was blockaded, the Germans used wood pulp instead.

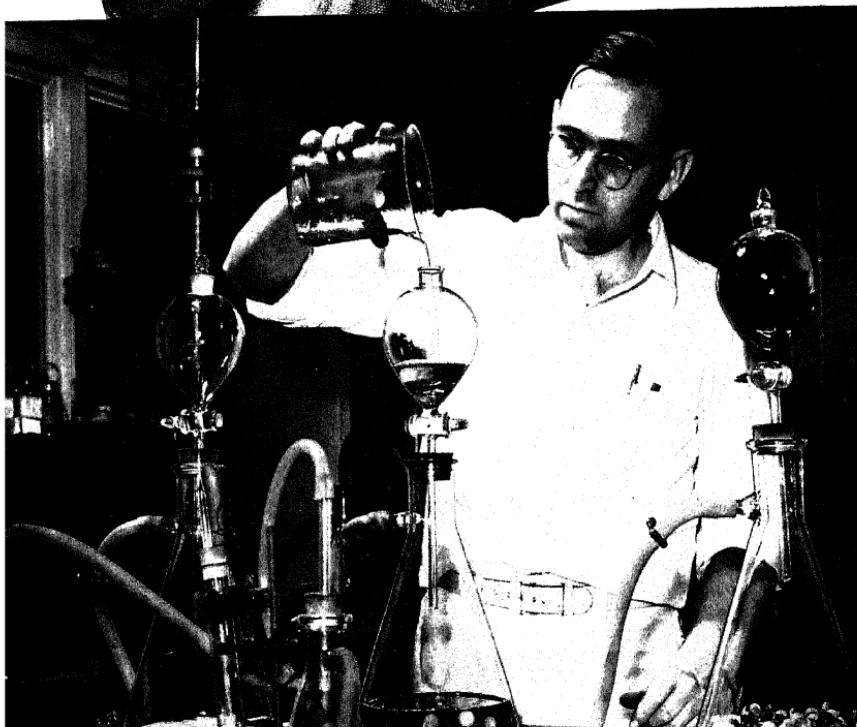
High explosives do not burn. They are fired by the shock from the detonator which is transmitted as a wave through their mass; and there is then an instantaneous molecular rearrangement, a transformation from solid to a gas which has far greater volume. This change is so quick that the gases have no time to escape from the container, even if there is an opening; and so the walls are shattered.

The first high explosive to be used extensively was picric acid. This dye, made from coal tar, gives to the hair and skin of men who work with it a yellow color which will not wash off, though the color disappears when they are no longer in contact with the materials. One great danger in using picric acid is the likelihood of its combining chemically with the metal of its container. Compounds are formed which may go off spontaneously, and then the rest of the explosive in the container goes off too.

Though, for such reasons, the use of picric acid itself as an explosive has been largely abandoned, it is still a step in the manufacture of ammonium picrate, which the U. S. Army employs under the name of "Explosive D." A detonation wave moves through a mass of ammonium picrate at a speed of 4.5 miles per second, producing a very rapid shattering action—what the ordnance officer calls "brisance." It is therefore used



FROM THE WORK OF ANCIENT
ALCHEMISTS COMES MODERN
CHEMISTRY
(see page 11)





CABLE SPlicer POWERED BY EXPLOSIVE, IN USE BY A LINEMAN

to fill armor-piercing shells such as are fired from big naval and coast-defense guns.

Though the detonation wave travels through it more slowly, TNT, the common name for trinitrotoluene, is the most widely used high explosive today. Actually it has less power than Explosive D, but it stands much rougher treatment. A bullet can be fired through TNT without exploding it. In appearance something like brown sugar, it melts at 176° Fahrenheit and pours like hot tar.

Coal tar was the original source of the raw material, toluene, which is treated with sulfuric and nitric acids. But of recent years plants have been erected in the United States for manufacturing toluene from gasoline. Since the material in the gasoline from which toluene is made is one of the things responsible for an engine's knock, the motorist gets a better grade of gasoline as a result of the extraction. There is plenty of raw material; for it is estimated that a gasoline production of 2,500,000,000 gallons yearly, a tenth of what it was in pre-war times, would be ample to furnish 2,000,000 tons of TNT.

Exploding TNT gives off a dense black smoke, because some of the carbon atoms of which it is made remain uncombined in the reaction, and these black particles float in the air. But when it is mixed with ammonium nitrate, we have the explosive called "amatol," used in shells and bombs. This is so insensitive that the usual practice, in plants where these shells are filled, is to drill a hole in the explosive with an ordinary pneumatic drill! Into this is placed the booster charge.

The very sensitive detonator, mercury fulminate, will not set amatol off, and that is why a booster is needed. When the shell strikes, the fulminate explodes and sets off the booster—either TNT or another explosive called tetryl. That in turn detonates the amatol; all, of course, in far less time than it takes to describe the process.

Lead azide is another compound used as a detonator instead of mercury fulminate. It is less likely to go off accidentally, and

it does not require mercury, most of which comes from Spain. There is plenty of lead in the United States.²

In addition to the use of explosives as a propellant in guns, there have been many proposals for electric cannon, with magnetic coils, or solenoids, pulling a steel projectile through the barrel to start it on its way. In fact, explosives are fairly expensive sources of power, the same amount of which can be produced much more cheaply as electricity. But the trouble with electric cannon, which sometimes look most attractive on paper, is that the power cannot be released as quickly as with an explosive, unless with very elaborate and expensive equipment, like that for artificial lightning. Then the lack of portability is another objection; so the electric cannon has never proved practicable.

Many peacetime uses of explosives have, fundamentally, the same object as their use in war—that is, to move large amounts of material easily and quickly. Blasting earth for reservoirs, cutting through mountains for tunnels and railroads, demolishing old buildings before new construction; all these are essentially, though from different motives, what the military explosives are employed for.

² Probably the most important name in the American explosives industry is that of Du Pont. The founder of the company, Eleuthère Irénée du Pont, learned about explosives when, in 1788, the famous French chemist Lavoisier took him into the royal powder works at the age of seventeen. After being imprisoned three times in the French Revolution, young du Pont managed to come to America with his father and a brother. At first intending to start a company for speculation in land, he noticed the poor quality of American gunpowder, and set up his own powder mill on the Brandywine Creek near Wilmington, Delaware. This was successful from the start. It furnished, for example, much of the powder used in the war of 1812. During the latter half of the nineteenth century and the first few years of the twentieth, the Du Pont concern grew tremendously, as did many others. In 1907 the Federal Government, under the Sherman Anti-Trust Act, prosecuted the company and forced its dissolution into three parts. These are Du Pont, Atlas Powder Company and Hercules Powder Company. In 1933 the American Cyanamid and Chemical Corporation organized an explosives division, and these four companies became the largest present-day explosives manufacturers. All of them, however, are important chemical manufacturers, with explosives as just a part of their total production.

In peacetime, corresponding most closely to the use of explosives as a propellant in guns, there are guns that have no lethal powers—unless they go off accidentally. The “velocity power tools,” made by the Mine Safety Appliances Company of Pittsburgh, are really guns. One, for instance, is a punch that can be used to make a rivet hole in a half-inch steel plate. It does not look much like a gun, but is a piece of steel, shaped in the form of an extra-fat letter C. A cartridge, similar to an ordinary blank cartridge, is inserted, the jaws of the C are placed over the plate to be punched, and the firing pin, on top, is given a tap with a small hammer. The cartridge explodes and the expanding gases, exerting pressure of 100,000 pounds, push the punch through the plate, leaving a smooth, round hole. One man can punch holes in girders with such a gun at a rate of thirty to fifty an hour.

A somewhat similar device, with a sharp edge that will sever a steel-wire rope an inch in diameter, is used for cutting cables. Rivets can be driven with a gun in which the cartridge explodes to drive the hammer against the rivet. Another device is an explosive-driven punch to drive rivets out of a structure. The illustration shows a cable splicer powered by explosive, in use by a lineman.

In all these velocity power tools the piston on which the expanding gases push is the bullet but, unlike ordinary guns, it never leaves the barrel. Since the gases are retained in the barrel, much of the noise of the explosion is eliminated.

A new method of using explosives for riveting was introduced to American industry in the summer of 1941, and has since been extensively applied in building airplanes and other war equipment. In a big all-metal bomber there are as many as 10,000 fastening points where rivets must be inserted, but which are accessible from only one side. Even a pursuit plane, of all-metal construction, has about eight hundred. In usual riveting, some solid support is held against the opposite side of the rivet to keep it in place as the hammer pounds on it and forms the head which holds it tight. With only one side acces-

sible, however, complicated equipment was needed, and a workman could place but three or four of these blind fastenings a minute.

The new rivet, originally invented by two Germans, Karl and Otto Butter, connected with the Heinkel airplane works, was brought out in the United States by Du Pont, who control the American rights. Two years' experimental work by Du Pont engineers brought it to a high degree of perfection. The design had to be adjusted to our standards; and equipment for controlling accurately the tiny amounts of explosive was planned and built. During 1940 the rivets were tested by the U. S. Army and Navy. Then a limited number were sold to a few large airplane manufacturers for actual trials.

The rivet, of aluminum alloy, looks at first glance like one of the usual kind. However, in the shank end there is a small cavity, in which there is a charge of explosive. In use, the rivet is placed in the holes made in the pieces of metal to be joined. Then an electrically heated riveting iron with a silver tip is touched to the rivet head. The heat transmitted through the rivet sets off the explosive, which spreads the shank to form a head on the other end, and the rivet is in place, installed in about two seconds. After the holes are prepared, a single workman can place fifteen to twenty rivets per minute.

The explosive charge is so accurately controlled that the expansion which it produces can be held to within limits of a fiftieth of an inch, state Du Pont engineers. They say that a large part of the great advance in aviation has been made possible by the all-metal design, using lighter metals, such as alloys of aluminum and magnesium. This, of course, requires thousands of rivets. In the Douglas B-19 bomber, the largest ever built, there are some 3,000,000 rivets. Many of these can be reached from both sides and installed in the usual way; but designers were hampered by having to keep this in mind, when other considerations might dictate construction requiring blind rivets. Thus it is expected that the new rivets will make possible great structural advances. They will have other uses,

too, and will probably soon be made of other metals, such as steel.

4

With the tremendous need for its products, oil is now a subject of great interest. Here, too, guns are used, not primarily for the protection of the wells against enemies but to increase the flow of the precious fluid.

An oil well is not the mere hole in the ground that many picture. Going down perhaps several miles, the walls of the well are usually cemented, and inside the cement is a casing of steel pipe. In many oil fields there are several strata from which oil may be drained, so it is customary in that event to drive the well down to the deepest. This is simpler, and more economical, than drilling a shallow well, emptying one layer, then drilling farther, emptying the next, and so on. While the drillers are on the job, they go right to the bottom and install the casing all the way down.

But oil cannot pass through a steel casing, and it is necessary to punch holes so the oil can leak through. The first device to accomplish this was a mechanical perforator, patented in 1903, consisting of a series of horizontal pointed pins, driven outward through the casing by a wedge pushed down inside. Then, in 1926, a patent was granted for a device which used explosives to do the same thing. Since then the gun perforator has been widely used in oil fields throughout the country.³

This perforator looks no more like a gun than does the velocity power punch. It is a long cylinder, of diameter from three to five inches, depending on the bore of the well. The sides of the cylinder are studded with as many as 24 firing units. Each unit is really a little gun, with barrel, powder charge and pointed steel bullet. After the cylinder is lowered to the correct depth, the guns are fired electrically, one at a time.

Since, however, the barrel must obviously be quite short to fit within the casing, there is a problem in getting the neces-

³ Largely by Lane Wells, Inc., of Los Angeles.

sary pressure behind the bullet. In a rifle the gases have the whole length of the barrel in which to expand and to build up their push. The perforator gun uses a quick-burning pistol powder, and the bullet leaves the gun so quickly that there is little time for this process to take place. Therefore, a shear disc is used—a metal disc between the powder and the bullet. The charge explodes, the gas pressure increases until it is sufficient to break the disc, and the gases then give the proper wallop to the bullet, driving it out of the barrel and through the casing, perhaps several layers of steel and cement.

When enough holes have been made in the casing, the perforator is pulled up and the oil flows. Finally, after all the available oil has been secured from this zone, a plug must be placed above that level in the well. If not, oil from a higher stratum would flow down, and out through the same holes. To place such a plug, the same rigging used for the perforator lowers the plug into place, with the setting tool above it. In this is another charge of explosive, set off electrically. The explosion releases a setting ram, which is driven down by a powerful spring, expanding the plug. A covering of synthetic rubber, which cannot be affected by the oil, holds tightly to the side of the well. Then the perforator is lowered again, holes are shot at the next level, and production resumes.

The perforators have other uses, too. In some places, oil percolates through a limestone layer. No casing then is needed, but, to increase the flow of oil, the limestone is treated with acid to enlarge the pores. Before acid is applied, the guns are used to make holes in the limestone, thus enabling the acid to penetrate more freely. Also, the gun perforator has been used to increase the flow, at depths beyond 3,000 feet, of natural gas in a well near Amarillo, Texas, from which helium is obtained for the Navy's blimps.

There are still other types of industrial guns. One, the subject of several patents, is an explosive circuit breaker. A wire passes through the charge of explosive. If there is an overload the wire gets hot, the powder explodes, and the circuit is

broken. One form of the device, patented in 1938, has a blank cartridge which separates the contacts when it explodes and also forces an insulating liquid, such as oil, between them, snuffing out any arc that might form.

Explosives play their part, too, in the finding of oil. Science has learned much about the structure of the earth by the way earthquake waves travel through its interior. In the same way, by making artificial earthquakes with explosives, oil geologists can often tell whether conditions below the surface of the earth are such that oil might be present. Seismographs some distance away record these waves, and the records then reveal, to the initiated, the character of the structure below the surface. Explosives thus have made it possible to predict the location of sulfur, oil, gas and even metals with considerable accuracy, at a great economy in time and expense.

III. *Fuel for Tomorrow*

Probably no better example of the growth of a vast industry using and processing a product formerly discarded can be found than in the case of the refining of gasoline from petroleum—and in the thousands of new compounds, many of great use and importance, derived from the same source. In the year 1859 there were seventy-eight “coal oil” and kerosene plants in the United States, employing fewer than 1500 workers who turned out their product to the value of \$6,398,000. In 1940, however, \$11,000,000,000 represented the total value, at the wells, of U. S. petroleum production, and the finished value was far higher.

In some way, vegetation in ages long past solidified to form deposits of coal, which is largely carbon. But by a process, the details of which are still a puzzle, some of the carbon atoms united with hydrogen to form what chemists call hydrocarbons. The simplest such compound is a gas called methane, which is made up of molecules each consisting of a carbon atom with four hydrogen atoms branching out from it. This is known as “marsh gas,” for it is produced by decaying vegetation in marshes. If you have two carbon atoms linked together, there can be six hydrogens attached to the pair, and then you have another gas, called ethane. With three carbons and eight hydrogens, you get propane, also a gas.

There is a whole series of these hydrocarbons, with the number of hydrogen atoms always equal to two more than double the number of carbon atoms. The fifth member, called pentane, boils at about body temperature; below that it is a liquid. As the number of carbon atoms increases, the boiling point gets still higher; so does the melting point. By the time there are

twenty carbons, the result is a solid at ordinary temperature. These higher hydrocarbons are commonly known as asphalt and paraffin. The liquids with the higher boiling points, having ten or so carbon atoms, make up kerosene; those of about seven or eight carbons, gasoline; and the gaseous ones are natural gas, piped from fields in Texas and Pennsylvania to many other parts of the country.

When the first oil wells were dug, in 1859, kerosene was needed to supply the millions of oil lamps that lighted the nation's homes. So the crude petroleum was distilled and the kerosene separated. In those early days, the gasoline was thrown away, since nobody knew of any use for it. Even as late as 1906 kerosene was the main product of the oil wells. But then the growth of the automotive industry increased the demand for gasoline; and as the production of gasoline, by the simple distillation process, forged ahead, there was left over more and more kerosene, as well as other compounds with the larger molecules. For them there was no market.

In 1913 Dr. W. M. Burton perfected his cracking process, which was first commercialized by the Standard Oil Company of Indiana. This marked a revolution in the refining business, and for a quarter of a century it dominated refining methods.

“Cracking” is just what its name implies; the larger molecules are divided into smaller parts. You cannot, for instance, just mix the parts together again and get what you started with, as you could with the products of straight distillation. In fractionation, after you had separated the kerosene, the gasoline, the paraffin, and so on, you could put them all back in a barrel in the right proportion, and you would have your crude petroleum once more. But cracking is really more than this for in the process the molecules are actually changed.

The yield of gasoline from a barrel of crude was more than doubled by the cracking method, which involves the use of both pressure and heat. Originally the temperatures used were about 700° Fahrenheit, and the pressure about six or seven times that of the atmosphere. But now temperatures of a thou-

sand or more degrees, and pressures of 60 or many more atmospheres—a thousand pounds or more to the square inch—are employed. These are applied in great towers, built like big guns to withstand the strain.

Thus, in less than half a century, the oil industry has undergone a complete reversal. The product that once was nearly useless is now of most value, and what was once the main product is converted into this former waste!

An important economic advantage of the cracking process has been that seasonal demands may be met more easily. With fractionating, when gasoline in the crude was merely separated, the ratio between gasoline and fuel oil was always the same. On the other hand, in autumn and winter more fuel oil may be wanted but in spring and summer it is the gasoline that people desire. There would thus be a shortage of one and a surplus of the other, so a large storage capacity would be required. Now, however, the proportions may be varied with the seasons. In summer more heavy oil is cracked into gasoline than in winter, when oil is used more directly as fuel. Actually most big plants are combination cracking and fractionating units, and both processes are used. First the gasoline that will come off by distillation is recovered in that way, and the remainder becomes "cracking stock."

Cracking, applied to molecules, "makes little ones out of big ones"; but what about the still smaller ones, those made up of three and four carbon atoms, which are gaseous? The number of these increases with cracking. When you break big rocks to make medium-sized ones for building, you have many still smaller fragments left over. Likewise, cracking produces fragments in the form of small molecules, which come off as gas. At one time this was used only as a fuel in the refineries. In some cases it was wasted, being simply burned as a torch at the end of a pipe in some safe part of the grounds.

These molecules are now made into gasoline by a process that is the exact reverse of cracking. It is called "polymeriza-

tion," and consists of putting together small atoms to make bigger ones; and this is also being used today in an increasing number of refineries, generally in conjunction with fractionation and with cracking.

Much of the gasoline for Hitler's mechanized war on land and in the air was produced by another synthetic process, the invention of Dr. Friedrich Bergius. This is called hydrogenation. Patents are held by the I. G. Farbenindustrie and, in the United States, by the Standard Oil Company of New Jersey, which built the first American plant in 1930, two years after one had appeared in Germany. In this country, high costs have restrained its development, but the Nazis were not so much interested in costs, since it made available for them gasoline for the Luftwaffe and oil for Diesel engines in naval vessels and tanks.

The process can be used in refining crude oil, but its chief development, in Europe, has been with coal and products of coal tar as the source. Finely divided nickel acts as the catalyst which makes the reaction possible. Under great pressure (250 times that of the atmosphere) hydrogen gas is made to unite with the molecules of the raw material, and the desired products are the result. There seems to be slight doubt that, without this process or one like it, Hitler would never have been in a position to plunge the world into war. However, it has also been used in England, in a plant which began operation in 1935, having an annual capacity of 150,000 tons of gasoline. Perhaps this has been greatly increased and plenty of gasoline produced by the Bergius process may have made possible many of the R.A.F. raids on the country, and even the plants, where it was started.

According to one report, 100 tons of dry coal, free from ashes, will yield by this method 62 tons of gasoline, 28 tons of useful gas, and a residue, partly ash and partly other carbon-containing matter. Another hundred tons of coal, however, is needed to operate the equipment.

Over a few decades the petroleum-refining industry has completely changed. Before 1913 it was simply a business of processing; all that the refiners did was to separate materials which nature gave them mixed together. But cracking, polymerization, hydrogenation, and many other related processes have turned refiners into chemical manufacturers. This has been made possible by chemical technology, which in turn has required huge investments, both in original research and in the elaborate equipment demanded by the methods. Here again is an example of the way in which a large industry has been able to accomplish what the small independent producer could not possibly afford.

Along with this improvement in the refining of gasoline has come another great achievement—the elimination of “knock” and the production of the high-quality gasoline that is needed for modern aircraft.

The 1912-model Cadillac offered the public several advances. The self-starter was one. But the ignition system of its engine was better, and the compression pressure was higher than had been used before. This resulted in greater power and efficiency. It had been realized that increased compression raised the efficiency of an engine, and 1912 engines had double the pressures used originally, but this Cadillac was the first which actually reached the limit of the fuel—indeed, it had not been realized that there was a limit! The result was that the engine began to knock, and engineers immediately realized that here was an obstacle in the path of further progress. So, in the laboratories of General Motors, under the direction of Charles F. Kettering, who was responsible for the self-starter, research was begun, to conquer knock.

In the first stages, it was determined that knock was caused by gasoline in the cylinders burning so rapidly that the expanding gases actually pounded on the walls of the cylinder. Thus, it was not the engine but the fuel that caused knock.

Next came the problem of eliminating knock, a task entrusted to Thomas E. Midgley, Jr., and his assistant, T. A. Boyd. It seemed as if making gasoline dark in color might reduce it, since excessive heat was a contributing cause and dark colors would absorb heat. Midgley and Boyd added a little iodine to the gasoline, and sure enough, the knock was gone. But iodine was expensive, and besides it had a bad effect on the engine. Then it was learned that color did not make the iodine effective; rather it was some quality of the material itself.

More than 33,000 separate compounds were tried before the best was found. This is tetraethyl lead, a chemical that had been made in Germany. One chemical firm could supply it—at a cost of \$585 a pound! At that price about five dollars' worth would be required for a single gallon of gasoline, so tetraethyl lead was hardly practicable. But its high cost had been a result of rarity, and it was rare because there was no demand. The demand once created, it could be made from alcohol and lead at a reasonable cost.

Still another chemical was needed. Tetraethyl lead, by itself, forms lead oxide, which deposits on the spark plugs, valve seats and stems. To prevent this, ethylene dibromide was added, to combine with the lead as it burned. Thus a gaseous compound was formed which would discharge with the exhaust.

This step required in turn large amounts of bromine, and chemists looked longingly at the ocean. Even though sea water contains only about 66 pounds of bromine to a million pounds of water, there is still plenty of bromine there. So a ship, christened the S.S. *Ethyl*, was fitted as a floating laboratory, and a practicable process for extracting bromine from sea water was devised. In 1933, ten years after the first ethyl gasoline had been placed on sale, a plant was established at Kure Beach, on Cape Fear, N. C., where coast and current conditions were favorable to providing the water and carrying away that from which the bromine had been removed.

Ethyl fluid, now used in most of the gasoline sold, controls the rate of burning of the fuel. It prevents the gasoline from

burning too rapidly, especially at high temperatures. Surprisingly enough, even though the motor runs cooler, it also delivers more power. The reason is simply that more heat units are changed into power, instead of being wasted through the exhaust and the cooling system.

The way the gasoline molecules are built out of atoms has a lot to do with engine knock. For example, there is one hydrocarbon, called octane, which has eight carbon atoms in a chain. At the ends of the chain, and on each side of each carbon, hydrogen atoms are attached, making 18 hydrogens in all. This normal octane knocks very badly. Yet if the same atoms are switched around a little, with the chemist's seeming magic, the qualities may be vastly improved. Iso-octane has the same eight carbons and 18 hydrogens, but they are placed differently. Here there is a chain of five carbon atoms, from which other carbon atoms, with hydrogens attached to them, branch off. The more branches there are, in general, the better is the gasoline.

Iso-octane was once regarded as a "perfect" fuel, and from it we have the term "octane number." It has, by definition, an octane number of 100, while heptane, with an unbranched chain of seven carbon atoms to which 16 hydrogens are attached, is rated as zero. To determine the octane number of an unknown gasoline, it is burned in a single-cylinder test engine and compared with a mixture of heptane and iso-octane used in the same engine. The octane number is the percentage of iso-octane in the mixture which produces a similar amount of knock. Thus, if the knocking of a gasoline under test is equaled by a mixture of 70 per cent iso-octane and 30 per cent heptane, it has an octane number of seventy.

When this test was first devised, iso-octane cost \$300 per gallon—rather too expensive to use in routine tests. So secondary standards were made, of other compounds, which were treated against it; and they in turn were compared with the new gasoline. In fact, this is still done to some extent. Iso-octane now costs \$9.00 per gallon, and heptane twenty-five dollars.

However, chemists have produced fuels superior to iso-octane, one of which, called triptane, has the same number of carbon and hydrogen atoms as heptane—the zero of the knocking scale. Though its price has been greatly reduced—to a mere \$40 from \$3600 per gallon—it is not likely to come into extensive use unless some cheap process of making it is found. According to Dr. Gustav Egloff,¹ triptane gives a power output 50 per cent better than iso-octane.

The simplest hydrocarbon, methane, with one carbon atom, and ethane, with two, have octane ratings above 100, while propane, with three, has a 100 rating. The trouble with these, however, is that they are gases; and in order to keep them in liquid form for use in an engine they must be held under high pressure in heavy steel cylinders. Despite this disadvantage, their fine performance, and the fact that they are easily obtained from many oil wells and from natural gas, has resulted in their use in stationary engines, buses, trucks and even pleasure cars. They have been used in Germany, where filling stations were established to provide compressed gas on the road. Probably the heavy tanks needed to hold the liquefied gas will preclude its use in airplanes.

But 100-octane gasoline can be made, and is being made. It has powered the airplanes of the United Nations, giving them a great advantage over those of the Axis Powers, which were unable to duplicate it. It enables engines of our fighting planes to operate with high-compression ratio and the greatest efficiency. Dr. Egloff stated that on December 1, 1941, 100-octane gasoline was being produced in the United States at the rate of 168,000 gallons per day. This is 40,000 barrels, a figure which is being tripled. Every hour an average military plane will use 3.5 barrels, so a production of 120,000 barrels daily is enough to keep 35,000 planes in the air an hour each.

What 100-octane gas will do for an airplane is shown by tests made by the Australian Institute of Automotive Engineers on a Koohoven (Dutch) FK59, a two-seater reconnaissance

¹ Director of research of Universal Oil Products Company.

bomber with a Bristol-Mercury XV engine. It had to be modernized to handle the powerful fuel, for an engine designed for 87-octane gas, as this had been, will not run appreciably better on the 100-octane. That means, of course, that even if you could get such high-quality gas for your car, it would not be of any advantage to use it. But future models surely will have engines that will use such fuel, which then may be widely available; and their performance will be vastly improved by this war-dictated research.

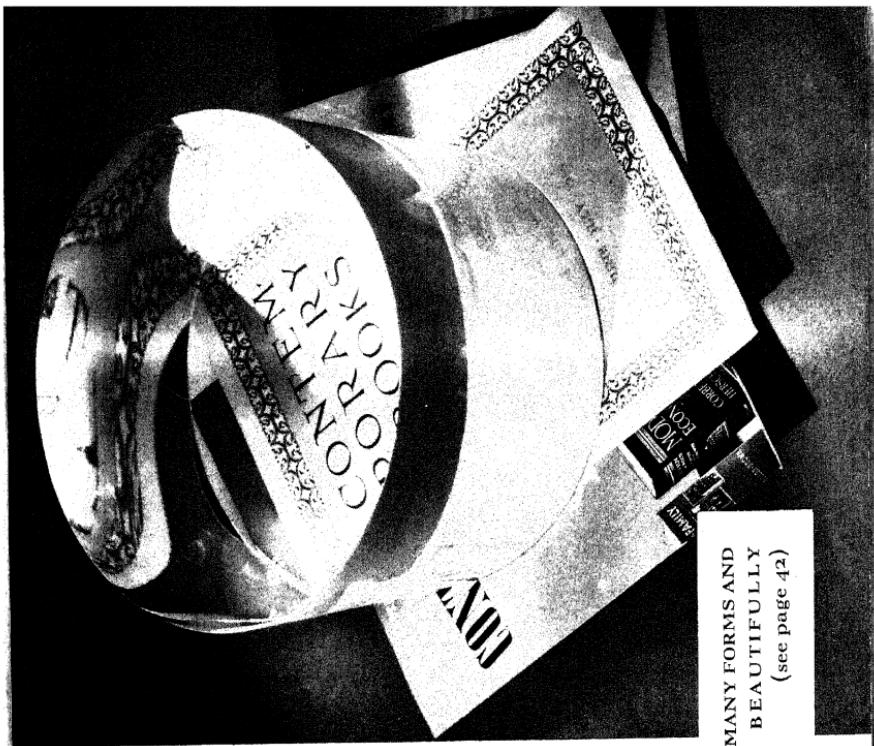
The Australian tests showed that the bomber with 100-octane gas had a maximum speed of 260 mph, compared with 236 on the old fuel; engine output was raised from 830 hp to 1050 hp and the absolute ceiling was increased from 32,800 to 36,700 feet. A more complete summary of their findings is shown in the accompanying table.

100 Octane vs. 87 Octane Gasoline in Airplane Performance

AIRCRAFT	87 OCTANE	100 OCTANE
Maximum speed at 2,750 rpm.	236 mph	260 mph
Altitude for maximum speed	15,700 feet	17,300 ft.
Rate of climb at sea level	1,490 ft./min.	2,180 ft./min.
Rate of climb at 6,500 feet	1,630 ft./min.	2,360 ft./min.
Rate of climb at 19,500 feet	1,220 ft./min.	2,060 ft./min.
Time of climb to 6,500 feet	4.2 min.	2.9 min.
Time of climb to 26,000 feet	19.4 min.	12.2 min.
ENGINE		
Maximum output	830 hp.	1,050 hp.
Maximum power height	14,450 ft.	15,580 ft.

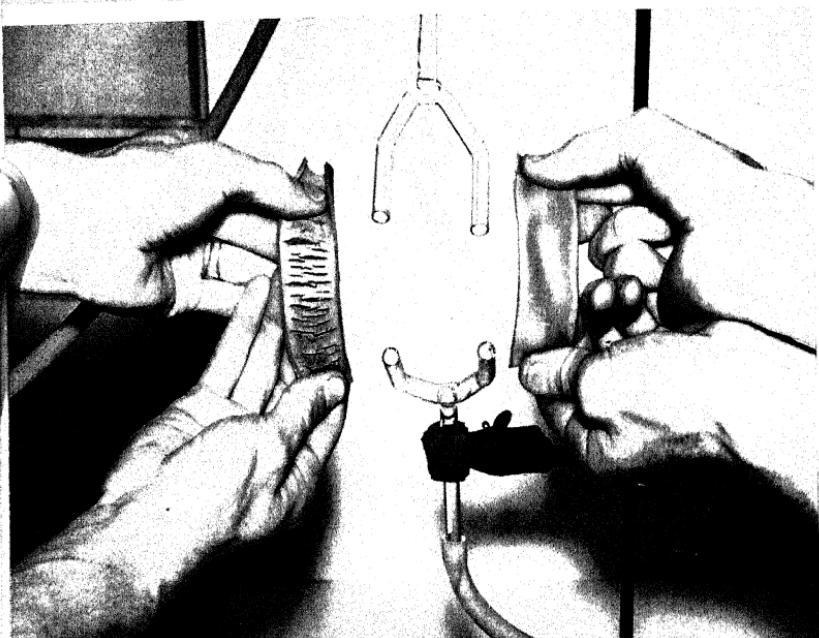
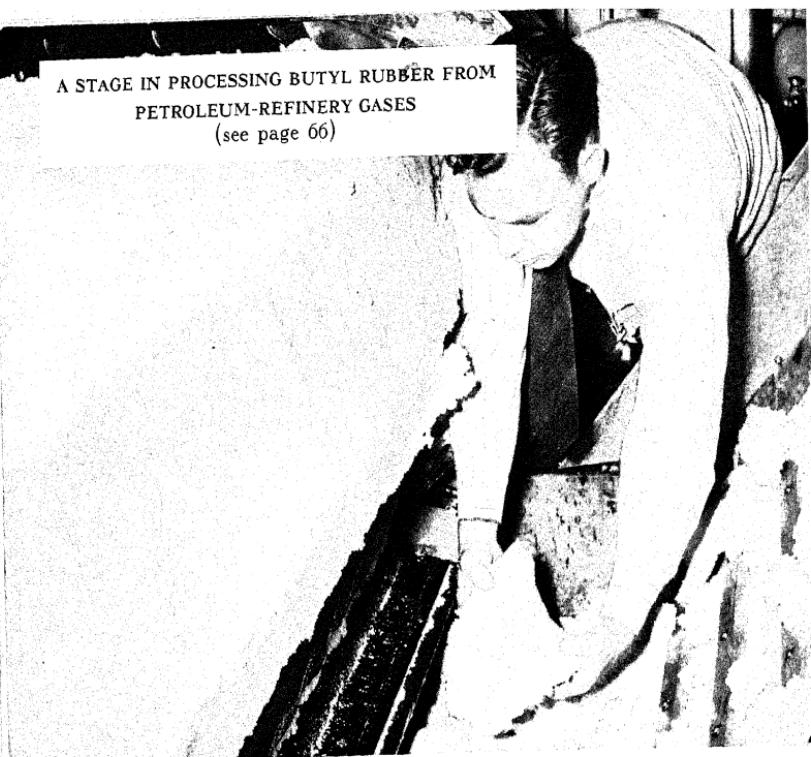
It is easy to describe the process by which these new gasolines are made synthetically as "just pushing molecules around"; and that gives some idea of what the chemist does, though it tells nothing about the years of work and research, in great laboratories, which have shown the way to do the pushing.²

² In the original thermal cracking process, as introduced by Burton in 1913, heat and pressure were the main agents. In the last few years catalytic cracking processes have come into commercial use, employing those same "chemical



PLASTICS COME IN MANY FORMS AND
COLORS — SOME BEAUTIFULLY
TRANSPARENT (see page 42)

A STAGE IN PROCESSING BUTYL RUBBER FROM
PETROLEUM-REFINERY GASES
(see page 66)



OXYGEN SOON CRACKS A TUBE OF NATURAL RUBBER, BUT ONE

The molecules are split into pieces, then rearranged. In many cases this rearrangement results in an entirely different type of molecule; one which, instead of having a chain structure, is built like a ring. In other words, the head of one of these chains is made to bite its tail and to hang on, like the mythical hoop-snake trying to swallow itself. Another process, called "hydro-forming," starts with naphtha, or gasolines of low-octane number, and converts them into high-octane gasoline, having, predominantly, the same ring structure. It does it, under the influence of a catalyst, by re-forming the gasoline in the presence of hydrogen. Unlike hydrogenation, however, the hydrogen does not combine with the gasoline molecule—rather, some of the hydrogen already there is removed to make other compounds.

Still another process, related to these, takes the chain hydrocarbons, with at least six carbon atoms, and winds them into a ring like that of a chemical called benzene (which is one of the most important of chemical compounds) and its derivatives. The catalyst is an oxide of chromium, molybdenum, vanadium or titanium, in a base of alumina. This process has been of particular importance because one of these benzene relatives is toluene, the basis of trinitrotoluene, or TNT, most used of war explosives. In the United States early in World War II, one commercial unit alone was capable of producing 30,000,000 gallons of toluene annually, while, for the year 1942, a production of 70,000,000 gallons by such a process was projected. With another 30,000,000 from the coke industry, this made 100,000,000 gallons, or five times the amount that the Army asked for in 1918, when toluene was all obtained from coal tar.

The modern tendency in gasoline refining, it has been pointed out, is to use more and more of the catalytic reactions, because they can be so much more easily controlled, and are cheaper to operate, than the old ones with heat and pressure. The gasoline

parsons" described in Chapter I. Several such methods are available, including the Houdry process, used by the Sun Oil Co., and those of the Standard Oil of New Jersey and of the Universal Oil Products Company.

34 SCIENCE REMAKES OUR WORLD

thus made does not contain so many different hydrocarbon compounds as the old products. As Dr. Egloff puts it:³

The ideal would be a single hydrocarbon giving far greater power output than any of today. Combustion would then be controlled to an exactness impossible with today's gasolines, which contain hundreds of hydrocarbons each competing for the oxygen available. The results are not conducive to high efficiency.

What this may mean for the future of air transportation is difficult to predict, but fuels of far greater anti-knock properties are possible, as well as more efficient engines and plane designs, tremendous speeds and airplanes carrying 1,000 or more passengers.

And this is all a result of the fact that gasoline stopped being just a product extracted from a natural liquid, and became a synthetic product, custom-made by the chemist to fit his needs!

As this tendency develops, compounds formerly, or even now, regarded as unsuitable for such molecule-juggling will be used. As a forecast of what the future may ultimately bring, we have the experiments of Dr. Ernst Berl, chemist of the Carnegie Institute of Technology in Pittsburgh, who said at an American Chemical Society meeting that "it is now possible to imitate nature and to carry out the production in a very short time, from carbohydrates, of bituminous coals which have exactly the same properties as natural bituminous coals."

Carbohydrates are compounds such as starch and sugar, and cellulose, which forms the basis of wood fiber. They contain carbon, hydrogen and oxygen, the last two in the proportion of two to one, as in water. Oils can be made from them in the laboratory as well, Dr. Berl reported.

In doing this, the chemist performs the same "miracle" that nature did over the ages, but does it in a matter of hours. By what Dr. Berl calls a "rather simple process" which involves heating the carbohydrate under high pressure with limestone, he accomplishes the change. If this can be perfected and commercialized, then perhaps farms, rather than mines and oil wells, will supply our fuel for tomorrow.

³ *Journal of Chemical Education*. December, 1941. "Modern Motor Fuels," p. 582.

IV. *The Realm of Plastics*

Because modern synthetic plastics are so completely different from construction materials the world has previously known, it is rather difficult to find a concise definition which includes all members of the class, as it is conceived in the present day. Mr. Webster's "a substance capable of being molded or modeled, as clay or plaster," is hardly acceptable, because clay and plaster are not plastics in the modern sense. Since these are neither animal, vegetable nor mineral, they have been referred to as "the fourth kingdom."

There are natural products that have some of the properties of plastics—substances like shellac, which is produced by the lac insect of India; natural resins such as amber and rosin, and bitumen, which is a black, mineral pitch. But, although these are still widely used, the modern plastics industry has produced a variety of synthetic materials that can be formed into any desired shape with pressure and heat. They can be made with a vast variety of properties, to meet specific needs.

Heat acts upon them in one of two ways; and as a result, the field of plastics is broken into two great divisions. One group is the "thermoplastics." These are softened when heated, and harden when cooled. But if they are again heated, they soften once more, and the process can be repeated time and time over. Members of the other class are "thermosetting." When the original material is softened by heat and formed to shape in a mold, it undergoes a chemical change; cross links are formed between the long molecules in which the atoms are strung together. This makes a solid, permanently infusible and insoluble mass, unaffected by further application of heat unless at a temperature sufficient to burn the material.

In addition to these two classes, plastics authorities some-

times distinguish a third, "elastomers." These are plastics which can be softened with heat and molded to shapes desired. Some can be vulcanized. In this process, sulfur atoms are hooked on to the molecules, making them more solid and permanent, and the result is a substance like rubber. Though the elastomers might well be considered in a discussion of plastics, we shall leave them, on account of their growing importance, until later on.

The modern plastics industry began in 1868, while General Grant was president, with a printer in Albany, N. Y.—and a billiard ball! Up to then these balls were made of real ivory. But ivory from elephants' tusks was expensive; and the Albany printer, John Wesley Hyatt, discovered that a material resembling it could be made from cotton; a compound called cellulose. Like a great many useful substances, the molecules of cellulose are polymers, long chains of the same unit repeated again and again. This unit is a rather complicated arrangement of six carbon atoms, seven hydrogens, two oxygens and three sets of oxygen and hydrogen linked tightly together, called "hydroxyls." These hydroxyl groups are characteristic of the chemical compounds known as alcohols, and their importance lies in the fact that they can, in chemical reactions, easily be replaced with other groups, producing "esters."

When cellulose is treated with sulfuric and nitric acids, nitrate groups, each consisting of a nitrogen atom and three oxygen atoms, replace the hydroxyls. If this "nitration" process is carried to the point where some five-sixths of the hydroxyl groups are replaced, we have guncotton, an explosive. But if the process is halted when only 30 to 70 per cent of the groups have been changed, pyroxylin is obtained. Hyatt found that this could be mixed with camphor to make a thermoplastic, though he would hardly have recognized that name. He called it "Celluloid."

First, billiard balls were molded of Celluloid. Then came

plates for false teeth. In 1872 the Celluloid Corporation was founded, and thousands of uses were found for the material. It played a vital part in the development of amateur photography; and in the movies, too, when the company in 1890 perfected machines for making continuous transparent Celluloid films. Before that, George Eastman's first Kodaks had used paper film; but the new cellulose-nitrate film was a great improvement, ready for the experiments of C. Francis Jenkins, Thomas A. Edison and the other motion-picture pioneers of the nineties.

Because of its close relation to guncotton, it is hardly surprising to find that Celluloid is highly inflammable.¹ Its inflammability can be reduced with the addition of other compounds; but the Celluloid Corporation made a great step in 1910 when they introduced cellulose acetate, which burns but slowly and has now superseded the nitrate for amateur motion-picture and X-ray film. (Professional motion-picture film, always handled with special precautions and by experienced persons, still employs cellulose nitrate.) With a host of other applications, Celluloid is still important in the plastics field, and in the United States some 13,000,000 pounds are produced each year. That produced by Du Pont is known as Pyralin, while Amerith is another name for the cellulose nitrate of the Celluloid Corporation. Cellulose acetate also is now made by several manufacturers. The form made by the Celluloid Corporation for the molding of various products is called Lumarith. The Eastman Kodak Company, using large quantities for film, likewise went into the plastics business and they produce it as Tenite.²

During the past century, in many products such as combs and telephone receivers, where plastics serve today, hard rub-

¹ Celluloid billiard balls sometimes exploded with a loud report. This caused a Colorado pool-room operator to complain. He said that he didn't mind, but it made his customers all pull out their guns.

² As we shall see in the next chapter, cellulose acetate can be spun into fibers to make a synthetic silklke yarn. One form, called Celanese, is produced by the Celanese Corporation. A similar fabric is Eastman Acetate rayon, product of the Tennessee Eastman Corporation, plastics subsidiary of the Eastman Kodak Company.

ber, also known as vulcanite or ebonite, was used. The usefulness of rubber lies largely in the fact that it is both thermoplastic and thermosetting. Pure rubber softens with heat, stiffens with cold—a property which limited its use in the early days before the discovery of vulcanization. This is accomplished by adding sulfur. Soft rubber can be formed to any shape desired, such as that of an automobile tire; then sulfur is added to vulcanize it, and it sets into that shape. If only a little sulfur is used, the result is still soft and "rubbery." But if given all the sulfur that it can take, a hard mass results which is hard rubber. Black originally, it turns to a dirty green when exposed to sunlight and has a rather unpleasant odor. It absorbs oils and greases, and is brittle, so it must be made fairly thick to give the required strength. Widely employed when there was nothing better, it is not surprising that modern plastics have made it practically obsolete.

The first serious challenge to the supremacy of Celluloid and hard rubber came about 1900, when Bakelite was invented by Dr. Leo H. Baekeland. Belgian by birth and American by adoption, he had already achieved fame as the inventor of "Velox." This was the photographic paper that, for the first time, made it unnecessary for photographers to wait for sunshine when making prints from their negatives.

Baekeland took two compounds widely known as disinfectants. One was the gas, formaldehyde, generally used in a water solution called formalin. The other was carbolic acid or phenol. These react in the presence of a catalyst, and join together while a molecule of water splits off. At first they form molecules in long chains. If the reaction is stopped at this point, the material is a heat-softening plastic. The threadlike molecules, held together by physical forces which can be broken down with heat, can then slide against each other. As they cool, however, the attractive forces again hold them together and the

material becomes hard. This in general is the characteristic of any of the thermoplastics.

The chief use of phenol-formaldehyde plastics in this form is to make an intermediate product which can be ground into powder for molding. The manufacturers sell such powder to other firms who do the molding. In this way the plastics industry resembles the steel industry, where one group of manufacturers make the material and supply it to others, who manufacture it into useful products and structures.

In the molding process, the powder is subjected both to heat and pressure, and it becomes a syrupy liquid, which is forced between the dies that mold it to shape.³ Then the final stage of the reaction takes place. Additional chemical links are formed, this time crossing from one chain to another and making a three dimensional lattice, a resin, which cannot be broken down merely by the application of heat. Enormous molecules are thus built. Most people think of a molecule as something far below the limit of visibility of the microscope. However, the main pieces of your telephone handset, which is made of phenolic resin, are each, according to one point of view, single molecules, which you can easily see and handle.

Resins of this kind, in the molded variety, are not available except in dark colors such as black or dark brown. When the catalyst which activates the combination of the phenol and formaldehyde is acid, the linkage takes place slowly and can be stopped where desired. But it is possible to prepare a liquid form which can be introduced into molds. Then the material, when heated, sets at a temperature well below the boiling point of water; and molded objects made from the cast phenolic resin are often brought to the right shape by being put through a machining process of sawing, turning, or threading. Such castings can be made in a wide range of transparent or colored forms.

³ Usually finely ground wood, called "wood flour," is mixed with the molding powder. This acts as a filler, decreasing the cost, and also making the final article stronger.

In addition to the familiar products in everyday use, many articles are made from these phenolic resins, both molded and cast, which play an important part in industry, but which the public seldom sees. Gears are an example. In 1908 the General Electric Company introduced a gear made of a pile of cotton sheets, cut to shape, and squeezed tightly between two steel plates by bolts running from one to the other. The cotton could soak up oil and keep the gear permanently lubricated. Since the use of such a gear avoided contact between metal and metal, it was very quiet. As an outgrowth of this there came a gear in which the compressed cotton is bonded by means of phenolic resin. This was produced under the name of Textolite. In recent years, the General Electric has made Textolite (and other plastics as well) for a variety of other and more general purposes and has become a leader in the industry. One novel use of Textolite is for women's high heels.

Cast phenolic resins, because of their strength and resistance to water and many chemicals, have been used recently for such hard tasks as guiding, thousands of feet underground, a string of casing, weighing perhaps hundreds of tons, into a newly drilled oil well. And experiments have been made, quite successfully, in using the material for dies which, under pressures of as much as a ton to the square inch, shape aluminum parts for airplanes. Such dies, even after being used hundreds of times, are as good as new.

One hard industrial use for bearings is in the necks of the rolls used in steel mills. These rolls perform the same function as the home rolling pin—except that the steel-mill rolls squeeze thick blocks of steel into thin sheets, which is rather more strenuous. The bearings have to withstand pressures from 500 pounds to as much as four tons to the square inch; and formerly they were made of the customary bronze or Babbitt metal. Bearings of laminated phenolic plastic are now used, and they wear upwards of fifty times as long. In addition, they are more efficient in their operation, and so give power savings of from 15 to 60 per cent in operating the mill.

Instead of phenol, a compound of carbon, oxygen, hydrogen and nitrogen, called urea, can be combined with formaldehyde to link the various atomic groups together to form the lattice structure of the big molecule. Such urea-formaldehyde plastics can be made transparent or brightly colored; they are odorless and tasteless. Like their relatives from phenol, they set with heat. In finished form they are not as resistant to continuous heat, however; but in many uses this is not a serious drawback. The trade-marked product "Beetle-ware" is made of urea-formaldehyde.

An important use of the formaldehyde resins is in making plywood. For some of the lighter planes flown in World War I, plywood was used, but in those days the thin wooden sheets of veneer were fastened together with animal or vegetable glue, which easily failed. Now, however, a solid and permanent bond may be made with either urea-formaldehyde or phenol-formaldehyde resin. In the original method, plastic-impregnated sheets of tissue paper are interleaved between the layers of wood; then a pressure of about 200 pounds to the square inch, at a temperature of around 550° Fahrenheit, is applied for about ten minutes, forming a tight joint.

Unlike the glued joints of older plywoods, such a bond is stronger than the wood itself. In more recently developed methods, the plastic is spread on both sides of the wooden sheets, in solution in water or alcohol, and then dried. After that the sheets are pressed together. Heat usually is applied, and this is necessary for phenolic resins, though a method of cold pressing, with the urea type, has been devised. The cold-press method is especially adapted to use in small shops where expensive and special equipment for hot pressing is not available.

It is even possible to apply heat to plywood assemblies by radio. This is basically similar to a device, used in the treatment of some diseases, by which very short radio waves are sent through the body and are absorbed by the tissues, heating them and killing certain germs that may be causing trouble. The plywood assembly can be bent, even into complicated

shapes, between two dies which also act as electrodes. When the device is turned on, electrical waves between the dies generate heating currents which flow through the plastic interlayer, making the heat just where it is needed. Even if the assembly of plywood is very thick, the radio waves pass through, whereas, with direct heating, it might be hard to get the warmth into the center without having some bad effects on the outer layers.

Rubber balloons are used for forming the complicated plywood fuselage and wing sections of airplanes, especially of the training types. These have been widely referred to as "plastic" airplanes, though that is hardly correct, since the plastic is only a small percentage of the total structure. Thin wooden veneers, with the interleaved plastic sheets, are laid over a form of the proper shape; then the rubber bag is placed on top and inflated with steam, giving at once heat and moderate pressure—enough, with the materials used, to make a tight bond. (The tightest fits are made with the phenols, but they require somewhat higher temperatures than urea plastics.) Plastic-bonded plywood has even been used by the British for first-line fighting planes. The tiny Navy patrol torpedo boats, making up what is popularly called the "mosquito fleet," also are made largely of the same material, which successfully withstands even the buffeting encountered at speeds of 70 miles per hour.

In World War I, some of the military planes were fitted with sheets of cellulose nitrate, the only transparent plastic then available, for small unbreakable windows. But in addition to its inflammability, cellulose nitrate is unstable when exposed to sunlight; and with age it also tends to shrink and crack. In great contrast are the transparent plastic noses of bombing planes today (like that shown in the Frontispiece), or the hoods for the cockpits of fighters, which sometimes are made in large-single pieces, precisely formed to shape, permanently clear and much lighter in weight than glass. These are generally of methyl

methacrylate, a plastic which goes back to the researches of a Darmstadt chemist, Dr. Otto Röhm.⁴

The basic synthetic process for making acrylic resins, which are produced from petroleum, coal, air and water, is fairly complicated; and methyl methacrylate is the most expensive of the plastics. However, its beautiful clarity and resistance to weathering make it supreme for use in airplanes. It is thermoplastic. It softens at about the temperature of boiling water. The sheets can then be bent down over forms and held until cool. Under pressure it will flow somewhat, even when cold; but if the parts are so mounted that they are not under pressure, there will be no distortion.

Because of the clarity of the acrylic resins, they can even be used for lenses, both for magnifying purposes and for eyeglasses, where they have the great advantage of being unbreakable. They are so transparent that light will pass through a rod of such a resin like water through a pipe—that is, light hits the surface always at such a low angle that it is totally reflected. For this reason the material is used to pipe light into dark places; the mouth of a patient seated in a dental chair, for example. This same quality makes it suitable for signs, which can thus be illuminated from the edge. If the lettering is engraved or stamped into the surface, it shows up in luminous words.

Often manufacturers want to show the operation of some piece of equipment; a telephone, a water meter, an electric razor. Then the casing may well be made of an acrylic resin, and it permits a beautiful demonstration. One of the outstanding examples of this kind was a Chrysler automobile body which Röhm and Haas made a few years ago out of Plexiglas.

However, the articles do not need to be transparent. Since the material itself is completely colorless, pigments can be introduced as desired, to give the most delicate shades. False

⁴ About 1900. In 1931 acrylic resins became available in the United States in the form of sheets, and in 1937 as a moldable plastic. Two forms in which it is widely used are Lucite, a product of Du Pont, and Plexiglas, made by Röhm and Haas. Acryloid and Crystalite are other names.

teeth, naturally tinted, have been made of these resins, and so have dental plates. In radio sets and automobile instruments, acrylic resins are used for indicating panels, with the numerals stamped in and colored. These panels also lend themselves to edge illumination.

In the automobiles of two decades or more ago, windshields were a source of great danger in a collision. The flying glass often produced severe injuries where otherwise the passengers might only have received a shaking. Then came safety glass, a sandwich made up of two sheets of glass as the bread and a sheet of cellulose nitrate or cellulose acetate as the ham. This was pressed together and heated, and the plastic layer held the glass tightly. Then, when the glass was broken, the windshield remained rigid, and the sharp fragments were not thrown around.

A better material was found among the vinyl resins, a class of plastics with applications as diverse as phonograph records, electrical insulation, women's hats, men's suspenders, and lining for beer cans. The particular form used for safety glass is a combination of vinyl resin with a material called butyraldehyde.⁵ It comes in sheets, cross-ribbed with slight depressions so that they will not stick to each other when piled. Pressed between glass and heated, it flattens out and becomes entirely transparent. A windshield so made will yield when you hit it, and the result may be only a bruise instead of a fracture.

Vinyl alcohol has been known for more than a century. It consists of carbon, hydrogen and oxygen, the characteristic grouping being an arrangement of a carbon with one hydrogen atom, attached to another carbon with two hydrogen atoms. Two chemical "bonds" hold these two groups together; but only one is needed, so the other is available for linking the groups together in forming the polymer. In the alcohol, the

⁵ Butacite is the name of this material as made by Du Pont, and Butvar as made by another manufacturer, the Shawinigan Products Corporation.

carbon to which the single hydrogen is attached is also linked to the characteristic hydroxyl (hydrogen and oxygen) group. But this can be replaced with chlorine to make vinyl chloride, or with an arrangement of three hydrogens, two carbons and two hydrogens (obtained from acetic acid) to make vinyl acetate. The chloride makes a rubberlike material that we shall meet later as Koroseal, produced by the B. F. Goodrich Company, and as Flamenol, the flame-proof G-E insulation for electrical wires.

The chief form in which the material is used, however, is a combination of the acetate and the chloride; what is called a co-polymer. Here the chain molecules contain links of both kinds. They may alternate, or most of the links may be made of one form. At the present time these plastics usually contain from 80 to 95 per cent of the chloride.

Like some of the other plastics, this material, known as "Vinylite series V" and, in fibers, as Vinyon, both products of the Carbide and Carbon Chemicals Corporation, has to be mixed with a plasticizer for use. It can be molded, with pressures from 1200 pounds to a ton per square inch and temperatures of 250° to 290° Fahrenheit. Or it can be extruded. Then the material, softened by heat and pressure, is squeezed through an opening like toothpaste from a tube. The plastic solidifies and takes a cross-sectional shape corresponding to that of the opening. In such a way, long ribbons or rods may be made. Essentially the same thing is done in making this plastic into fibers for fabrics. Then the openings, very small, are called "spinnerets."⁶

Alkyd resins, still another class, are made up of large and quite complicated molecules. Used largely for lacquers in finishing automobiles (in the form, for instance, of Dulux, made

⁶ War uses of late have taken up most of the production of vinyl resins. The fact that they will burn when held in a flame, but go out as soon as removed, is most important. This quality results from the presence of chlorin. The basic raw materials are natural gas, salt water, coal and air, which seem plentiful enough; but here again electric power is needed in large quantities, particularly in making acetylene, which enters into the process.

by Du Pont), their civilian applications have lately given way to war ones. With high gloss, excellent resistance to sunlight, the ability to stick tightly to metal and to retain their new appearance for a long time, they are now mainly used as a finish for the superstructure of naval vessels.

One of the most important of chemical compounds is benzol or benzene (not benzine, which is really a form of gasoline). It consists of a six-sided arrangement of six carbon atoms, to each of which a hydrogen is attached. This is often referred to as the "benzene ring," and is represented as a hexagon, which appears in the official insignia of the Chemical Warfare Service of the United States Army. Since any, or all, of the hydrogen atoms in the benzene ring may be replaced by other atoms or atomic groups, it forms the basis of an enormous number of compounds. If the top hydrogen is replaced by our friend the vinyl group (carbon and hydrogen, then carbon and two hydrogens) the result is vinylbenzene, otherwise known as styrene, named after a plant from which it was originally obtained.

Petroleum and coal are now the raw materials from which styrene is made. The first step is to make ethyl chloride and benzene, which are combined into ethylbenzene. Then this is "cracked" to produce styrene, which can be polymerized to polystyrene. Thus we have the plastic marketed as Styron by the Dow Chemical Company, Lustron by the Monsanto Chemical Company, and Bakelite Polystyrene by the Bakelite Corporation. It comes in the form of a molding powder, which can be softened by heat, then squirted into an injection press, where it is formed by pressure into the shape desired. Crystal clear ordinarily, it can be colored as desired.

The most remarkable property of polystyrene, however, is its extreme resistance to chemical attack. Even hydrofluoric acid, which dissolves glass, will not affect it, so polystyrene bottles are now used as containers for the acid. Polystyrene absorbs water so slightly that the most delicate measures are required to detect the absorption at all. Also, it is an excellent

electrical insulator, a sheet a thousandth of an inch in thickness being able to resist up to 3000 volts.

In describing the rapid development of plastics, it is impossible in a single chapter to cover them all. There are many other types—plastics made from milk casein, and from the soy bean, for example—which have important uses. With the intervention of the war, it is fortunate that plastics have been developed so extensively in recent years—making it possible, for instance, from a material formerly employed for men's garters, to fashion clothing that protects against deadly poison gas.

V. *Chemical Clothes*

Thanks to the chemist, the coming of war with Japan, with its complete stoppage of silk imports, did not have the effect it would have had at an earlier time. Out of the laboratories had come products not only equaling that of the silkworm but actually surpassing it. Large-scale production was forced on our industries and in peacetime they will now be in a position to continue to supply our needs. Like so many of our most modern scientific developments, however, the idea of synthetic fibers is not new. Robert Hooke, great English scientist of the seventeenth century and one of the first users of the microscope, studied many natural fibers with his powerful instrument, and in 1664 suggested that they might be made artificially. In 1734 the Frenchman, R. A. Réaumur, asked as a result of his researches on silkworms and spiders: "Silk is only a liquid gum which has been dried; could we not make silk ourselves with gums and resins?"

But it was 106 years until Réaumur's question was answered when a Manchester silk manufacturer, named Schwabe, tried making resins of such compounds as gelatin, egg albumen and a species of moss, then spinning them through fine holes into filaments. This device was the forerunner of the modern spinnerets for rayon, but the fibers were not satisfactory.

Then came Count Hilaire de Chardonnet, in France. He had been a pupil of Pasteur when that great man was studying the silkworm diseases—whence, it is supposed, came his interest in textile fibers. He made the first commercial synthetic fiber in 1884, and his results, when shown at the Paris Exposition in 1889, created a great sensation. First Chardonnet used pulp from the mulberry tree; then wood pulp and cotton cellulose were employed. The cellulose was treated with nitric acid

(making what was practically guncotton) this nitrocellulose was dissolved in alcohol and ether, and then spun through small holes. The method is still used occasionally, but it has been almost entirely replaced by others.

The viscose process, which has been and still is widely used, dates from 1892 when two English chemists, Cross and Bevan, found that certain compounds of cellulose could be made which were soluble in water. Because of the difficulty in handling the wet filaments, a centrifugal method of spinning was developed. Less expensive than Chardonnet's method, or still another—the cuprammonium process that had meanwhile been introduced—it had rapid development.

All these three methods have one point in common—the product is simply cellulose, the same as at the start, but regenerated after some chemical juggling. This, however, is not true in the case of the fiber now known as Celanese. It starts out with cellulose acetate, used for non-inflammable motion-picture film, which has largely superseded the old, dangerous Celluloid or cellulose nitrate.

Before the First World War two Swiss chemists, brothers, Drs. Henry and Camille Dreyfus, started producing cellulose nitrate. During the war they established a plant near London to make it for airplane "dope." (Planes of that generation had fabric wings, and these were "doped" to render them less inflammable.) Then Dr. Camille Dreyfus came to the United States, at the request of our government, to establish a similar plant. This was started at Cumberland, Md., but the war was over before it was completed. As the Dreyfus brothers had previously done some work on textile fibers, those experiments were resumed; and the result was Celanese.¹ The fibers are made by dissolving cellulose acetate in acetone, from which it is solidified, in thread form, in warm water or air.

A high luster was a characteristic of the first rayons, one to

¹ It first appeared in 1925, a year in which something over 51,000,000 pounds of rayon yarns of all types were used, only 1,620,000 pounds of which were Celanese. Fifteen years later, however, the total had risen to more than 390,000,000 pounds, about a third of which were acetate rayons.

which many people objected; so a process for removing the luster was devised. The removal, though, was not permanent, so it was an improvement when non-lustrous yarns were later produced. These yarns differ considerably in the amount of moisture they contain. Water causes the fibers to swell and to lose strength. However, they resume their strength when dry again.

It is interesting to see how, even before World War II, the use of rayon had replaced Japanese silk. In 1929 the United States consumed 59,100,000 pounds of raw silk for weaving and 48,500,000 pounds of rayon for the same purpose. But in 1939 the consumption of raw silk had dropped to 8,900,000 pounds, whereas that of rayon had increased to 285,700,000 pounds. So, even before war cut off our silk supply, we were becoming largely independent of it, anyhow, by using straw, wood pulp, or cotton as the original source of the cellulose raw material.

As a by-product of the rayon industry has come a very popular type of wrapping material, known as Cellophane when produced by the Du Pont Company, Kodapak when the Eastman Kodak Company makes it—and many other names. Cellophane is made by the viscose process, but, instead of being spun through spinnerets into threads, it is formed into sheets through a narrow slit. Often, too, these sheets are slit into fibers as narrow as a hundredth of an inch for use in textiles.

The casein from skimmed milk has been employed, especially in Italy, to make a synthetic fiber called lanital. In the United States it has been produced under the name of Aralac, and mixed with rabbit fur in the manufacture of felt hats. The casein fibers have less elasticity and strength than wool, which they resemble more than silk. They also stretch more than wool, particularly when wet. On the credit side, however, they are non-shrinkable, and are not attacked by insects.

The Ford Motor Company has been responsible for experi-

ments with a fiber made from soy beans. This, the "honorable bean" of China, can be grown easily in the southern parts of the United States. Many researches have been made into its use as a base for paints and plastics, so that much of the fiber, as will be seen, may be available as a by-product. The bean is crushed, the oil extracted. Then the meal is put through a salt solution which extracts the protein, and the residue is spun through spinnerets into a bath which makes the solution coagulate. The fiber has 80 per cent of the durability of wool.

There are also fibers made of synthetic resins, essentially the same as some of the plastics. One, Vinyon, is made up of links of molecules of great length, consisting of alternate links of compounds called vinyl chloride and vinyl acetate. The process of making the fiber from either coal or natural gas, and salt, water and air, was developed by the Carbide and Carbon Chemical Corporation, and the product is made by the American Viscose Corporation. As Vinyon is unaffected by molds or fungi, and is as strong when wet as when dry, it has many possibilities, though its use in clothing is limited by the fact that it begins to shrink at temperatures of 150° Fahrenheit, well below boiling. At about 175° Fahrenheit, too, the fibers tend to stick together, and this of course makes it difficult to iron. One novel use has been found for Vinyon, however—as fishnets. Along the Florida coast they caught twice as many fish as tar-impregnated cotton nets, and were as good as new after six months' use.

Striking for many reasons has been the development of Nylon by Du Pont, under the direction of Dr. Wallace H. Carothers, whose brilliant career was ended by death just when his achievements were showing fruit. In 1927 the company's chemical director, Dr. C. M. A. Stine, decided to set up as an important activity of his department fundamental research (as distinct from the applied research then occupying the various research divisions of the manufacturing departments), which

would be devoted to filling in gaps of knowledge. It was to explore new realms of chemistry in order to find facts that might perhaps be of future value to the company.

Dr. Carothers, with two years' experience behind him as an instructor of chemistry at Harvard, was brought to Wilmington, where he chose to work on the project of making big molecules out of little ones—the process technically called "polymerization"—by condensation from vapors. In connection with this he studied the structure of the molecules of long chains of atoms, a field which had been slightly explored up to then. A device called the "molecular still" made it possible to obtain longer molecules than any that had been made before. These polymers, which are formed of regularly recurring units, have been compared to a chain of paper clips hooked together.

Finally it was found that some of these products were solids, tough and opaque, which could be melted to thick transparent liquids. By dipping a rod into this molasseslike fluid and pulling it out again, threads are formed. But the most important thing the researchers noticed was that, even after these threads had cooled, it was possible to pull them to several times their original length—whereupon they became much stronger and more elastic. They could be tied into hard knots, a process in which the original filaments were easily broken. It was also found that these cold-drawn fibers, unlike most natural fibers and rayon as well, did not lose strength when they were wet.

What happened was revealed by X-ray studies of the arrangement of the molecules. They are really crystals; that is, the atoms are arranged in definite lattice formations; but in the original threads these molecules are helter-skelter. The cold-drawing, in stretching them and reducing their diameters, rearranges these crystals into parallel positions in which they are much closer together. Intermolecular forces then help to keep them so.

As a modification of the process of making the fibers from the melted material, it was discovered later that the compound could be dissolved in chloroform, then spun in air through

spinnerets, as with the cellulose-acetate rayon. Like the fibers pulled from the molten bath, they too could be pulled into the strong condition when cold.

Up to this point, the work had been mainly of theoretical interest, for the compounds melted at temperatures too low to permit their commercial use, and they dissolved too easily. However, one of the earlier compounds that Carothers had studied belonged to a class known as "polyamides." These he had put aside as being too difficult to handle; and, at this point, it seemed as if there was little hope of securing something commercially successful from his researches. For a number of months they were actually discontinued.

But then Carothers went back to his earlier problems; and he decided that the polyamides were best after all. Using the molecular still he prepared a compound which had a melting point of 383° Fahrenheit, a satisfactory figure. And when it was cold drawn, it equaled silk both in strength and pliability. This indicated that from the supposedly useless researches there might indeed emerge a useful material. Then came the search for the best polyamide, and on the last day of February in 1935 Carothers found the one that proved best. Chemically known by the long name of "polyhexamethylene adipamide," it was generally referred to as "66," figures which indicated the number of carbon atoms in the different parts. When it was decided that this should be used, a special effort was made, as W. S. Carpenter, Jr., president of the company, put it, to reduce to a minimum "the time between the test tube and the counter." About 230 chemists and chemical engineers, some from other departments, such as the one which had been making rayon, were transferred to wage a blitz campaign to put it into production. It was christened "Nylon."

Many problems were involved: the two raw materials, hexamethylenediamine and adipic acid, had to be produced in quantity. The former had been a laboratory curiosity, and the latter was produced commercially in Germany alone. But a successful method of making these from bituminous coal, water

and air was devised whereby, after the chemicals are mixed and combined under heat and pressure, the melted Nylon comes out as a ribbon to form on a chilled metal roller. The ribbon then is cut into chips, a convenient form in which to store it. When the fibers are to be made, these chips are melted again over a heated grid and blanketed with an inert gas; for otherwise oxygen from the air might cause undesirable effects. The liquid Nylon is pumped through spinnerets; the threads harden as soon as they strike the air, and are wound up on spools, which handle about half a mile of thread per minute. Then they are stretched approximately four times to give them their final form, which has great strength and elasticity.

From this point on, the threads are handled like any other textile. By October 27, 1938, hosiery manufacturers had tried the new yarn, some details of use which had produced unsatisfactory results in the first tests had been overcome, and it was announced that a large-scale plant was to be built at Seaford, Delaware. It started operation at the beginning of 1940 with a production capacity of 8,000,000 pounds of Nylon per year. This was less than five years after the "66" material had been invented—truly a remarkable achievement—and during 1942 a second plant, with equal capacity, was scheduled for full production. Plans were quickly made for increasing this even further, since the product has certain important war uses—notably, as parachutes.

Nylon is not a single material but a family of materials. So far, the form used for hosiery has received most attention; but it can also be used for tooth-brush bristles and tennis-racket strings, or, by modifying it chemically, it may be given somewhat different characteristics. Although it does not equal silk or wool in resilience (that is, in the ability to recover quickly from wrinkling), "Nylon yarn is the first truly synthetic fiber, and has a closer similarity in both constitution and properties to silk than has any other fiber," said Dr. Elmer K. Bolton, Du Pont chemical director since 1930, in a lecture. "For the first time the age-old problem of making a material closely re-

sembling silk appears to be solved. It has the appearance and luster of silk, although the degree of luster can be modified as desired. It possesses, moreover, the advantage of having greater uniformity than silk and, in addition, filaments of any desired size may be spun."

It is Nylon's strength when pulled that is one of its most important qualities. Even when wet it equals dry silk in tensile strength, while wet silk is considerably weaker. Its tensile strength exceeds that of wool, silk, rayon or cotton. In elasticity, too, it has remarkable properties, since it can be stretched 20 per cent before it will break. Again, it completely recovers after stretching, whereas silk or viscose rayon would remain partly stretched. Its melting point, about 480° Fahrenheit, is above that normally used in ironing, and when in a flame it does not blaze, but melts. It is not subject to mold or mildew, nor to attack of moths. Truly, the fundamental research that Dr. Carothers started in 1927 has had remarkable results!

A new fabric development that is one of the many promising products for a post-war world has been announced by the B. F. Goodrich Company. Now stockings can be made that will not run even if a nail is poked through them. Food packed in bags sealed with a hot iron, and colorful draperies which are so waterproof that they can be cleaned by squirting a hose on them, are other possibilities. Koroseal, which will be described in the next chapter, is the basis of this advance. Though the manufacturers point out that, strictly speaking, it is not one of the synthetic rubbers, it is related to them, and is often classified under that head.

The runless stockings are made in two ways. In one, fibers of the usual sort are coated with Koroseal. Another uses fibers of Koroseal mixed with silk. Probably either natural silk or one of its synthetic forms would work just as well.

Not only have synthetic materials replaced natural yarns

used as fabrics—they have also started to take the place of animal hides, or leather. The material used for such purposes is practically the same as Vinyon, but made up in sheet form instead of in fibers. Men's belts, suspenders, garters and wrist watch straps, women's shoes, aprons and braiding for hats—these are a few of the forms in which these vinyl plastics ² have been used for wearing apparel. All these can be made transparent, a novel quality in such articles; and so that feature has been emphasized, though it is not essential. Indeed, the same property of softening at a relatively low temperature, which imposes some limitations on the use of vinyon, makes it possible to mold vinyl plastic and to form the surface into any crinkly or other form that may be desired; and by adding coloring matter it can be made in any color, or entirely opaque.

Such material is non-inflammable, resists most chemicals, and absorbs little water, even after long soaking. It is flexible, but does not snap back immediately, like rubber. Rather does it have a lazy return, gradually resuming its original size and shape. When used for shoes, the material generally is perforated to allow ventilation and relieve the overheating that might occur because of its moistureproof quality. But because of the elastic properties, perhaps fewer shoe sizes would be needed if it came into wide use, since the uppers can give with movements of the foot. In cleaning the vinyl plastics a damp cloth suffices. Women's shoes have been made from them, and doubtless men's shoes will be along in the future.

This use of plastics for clothing is not as new as one might imagine. When Celluloid, the first of the modern plastics, was introduced in 1868, one of its early uses was in grandpa's Celluloid collar. This never wilted, and when soiled it could be cleaned with a damp sponge; but a "No Smoking" sign should really be worn along with it. Celluloid collars easily caught fire; and singed whiskers, or worse, resulted. Vinyl plastics have not yet been made into collars, but one use closely related is for a "dickey," or stiff shirt front, for wear with dress clothes or by

² Made by Carbide and Carbon Chemicals Corporation.

waiters. It can be made perfectly white and molded, with heat, to any kind of surface that is desired, simulating a fabric.

For women's costume jewelry, too, these synthetic materials have proved a boon, especially since the supply of Czechoslovakian glass was cut off in the early days of the war. Polystyrene is one; methyl methacrylate, known as Lucite or Plexiglas in two of its forms, is another. They have a high index of refraction; that is, light is bent considerably as it passes into them or out again; and the result is a sparkle like that of natural minerals.

Not only has chemical science shown how to make synthetic fibers—it has also revealed ways in which natural fibers may be changed and improved. For example, wool is in some respects an ideal material for clothing. But it has disadvantages, too. It cannot be washed without weakening, and one of its greatest enemies is the moth.

Now researches made at the Textile Foundation in the National Bureau of Standards have resulted in wool which gives moths indigestion, and which can be washed as readily as cotton. The process, known as "alkylation," has been developed under the direction of Dr. Milton Harris, and is similar in some of its effects to the vulcanization of rubber. It replaces weak connections between the sections of the long and complicated wool molecules with stronger and more resistant bonds.

The wool molecules consist of a chain of twenty or thirty different kinds of chemical substances, called amino acids. Connections between parallel chains are made by pairs of atoms of sulfur, and the number of these cross links determines the desirable properties of the fiber, Dr. Harris has found.

A chemical called thioglycollic acid, which used to cost \$17 per pound but is now available at well under a dollar, is able to pick out and sever the double sulfur bonds without affecting the long chains themselves. Fibers so treated are much weaker than the original wool, but exposing them to oxygen regenerates

the sulfur bonds, and the strength returns. However, the treated fibers may also be relinked with another group, known as an "alkyl residue." This consists of one carbon atom and two hydrogen atoms. Such "alkylated" wool is stronger than the original; it resists moths and mildew, and can be washed with soap and water without weakening.

Dr. Harris and his colleagues have found that moths thrive on ordinary wool because their intestinal fluids are extremely alkaline. Ordinary wool is highly soluble in alkaline solution because the double sulfur linkages are affected. On the other hand, the links made of the alkyl residues are very slightly soluble in alkalis. Thus moths may nibble the edges of fabrics made of alkylated fibers; but they do not eat holes clear through, for that would give them indigestion.

VI. *Rubber from Tree and Test Tube*

Like tobacco, rubber was an American contribution to the world. Columbus, on his second voyage, found the Indians playing games with a heavy black ball, which rebounded with such vigor that it seemed to be alive. The ball, he was told, was made of a gum obtained from a tree. But the world had to wait three centuries, until about 1800, before a commercial use was found for the material. It could be used, men learned, to rub out pencil marks—so it was called “rubber.” In the United States that name has stuck, replacing the old name, “caoutchouc,” which more or less accurately reproduced what the Indians called it.

Early nineteenth-century scientists began to wonder what the compound was chemically; and Michael Faraday, better known for his discovery of the fundamental laws which made electrical generators possible, supplied a partial answer in 1826. He showed that it consists of carbon and hydrogen in the proportion of five atoms of carbon to eight atoms of hydrogen—that is, its formula is C_5H_8 .

In those days rubber was not strong enough to be of much use. Raincoats had been made of it, but when they were exposed to cold weather they became stiff enough to stand by themselves. Heat, on the other hand, softened the material.

The discovery of the proper treatment came in the traditionally accidental style of the old-time kitchen inventor. In 1839 Charles Goodyear, in New Haven, was working on the problem of giving rubber the strength and resistance which it lacked. He had tried mixing sulfur with crude rubber, but without much success, though this was a step in the right direction. Accidentally he spilled some of the sulfur-rubber mixture on the kitchen stove, a tough mass formed—and this proved to be

the answer. Thus the process of hot vulcanization of rubber was invented, and the modern era of the usefulness of rubber began.

Then, and well into the twentieth century, rubber came from trees which grew in Central and South America, especially in Brazil. The most useful tree for the purpose was—and is—one called by the scientific name *Hevea brasiliensis*, the latter, the specific, part of the name denoting its country of origin. There the trees grew wild, natives tapped them, and from the latex which exuded they prepared the crude rubber.

As early as 1873 a start was made, under English auspices, in establishing rubber plantations in other parts of the tropics where the necessary conditions of a heavy and well-distributed rainfall and average temperatures of from 70° to 90° Fahrenheit prevailed. In 1900, however; only four tons of plantation rubber were produced, as compared with 26,750 tons gathered from the forests of Brazil. In 1912, as the use of rubber for automobile tires began to assume importance, Brazilian production was 42,410 tons, still surpassing the plantation production, mostly in Eastern lands, of 28,518 tons. The following year plantation production forged ahead, and it has remained in the lead ever since. During recent years the Brazilian contribution to the total production of well over a million tons, more than half of which was used in the United States, has been insignificant. But still the Brazilian tree, transplanted by botanical experts to new homes, was the main source.

Conditions being right, these trees develop in from seven to ten years. Then, with trunks about six inches in diameter, they can be tapped. When properly done, this process can be repeated every few days for many years. While some trees yield only four to five pounds of latex a year, others give as much as thirty pounds. Naturally, the scientists have tried to breed trees which give the maximum yield.

The labor situation in the East Indies has been favorable for rubber growing, with a large native population of Malays who are willing to work under tropical conditions at low wages.

In most of the American regions where soil and climatic conditions are right, the labor is lacking, for there is only a sparse population of native Indians in the jungles, and they have no desire to do such work. In the more settled regions, people of mixed blood, either Latin-Negro or Latin-Indian, want higher wages. Perhaps this is not an insuperable problem, however, for improved methods of collecting and processing the latex, in addition to the breeding of trees with higher yields, may make possible the production of natural rubber economically, even though labor does cost more.

Even before the war, the potential danger was recognized of having our supply of such a vital material as rubber come from such a great distance over seas that might be controlled by an enemy. Henry Ford, for example, sponsored a plantation venture in the valley of the Amazon. Afterwards, with the rubber supplies from the East actually cut off and the Indies plantations themselves in enemy hands, the situation was made clear to all. Over the last few years, a stock pile of rubber had been accumulated, but this was needed entirely for the American war machine. Now, finally, rubber trees are being planted in Central and South America. The rubber tree has returned to its native home; but since no appreciable yield can be obtained from a tree for five years at least, this does not afford an immediate answer to the rubber shortage.

Perhaps other plants can supply part of the deficiency. In theory, at least, protein molecules from soy beans can be rearranged to form chainlike molecules similar to rubber. A shrub known as rabbit brush, which grows to a height of as much as ten to twelve feet as a weed in waste lands of the West, is another possible source, to which Dr. T. Harper Goodspeed, of the University of California, has called attention. At least 25,000 tons of rubber could be obtained from its roots and stems, he believes, though it would not be as good as rubber from the *Hevea* tree, and would be more expensive to prepare. But the most promising source of natural rubber, other than *Hevea*, is the Mexican guayule shrub. This has been grown for thirty-five

years by the International Rubber Company in Texas, Arizona and the Salinas Valley in California.

Guayule (pronounced why-you-lee) planted in the spring can be harvested to some extent the following autumn. Densely planted, this yields about 1100 pounds of rubber per acre after a year. But if the plants are allowed to grow for four years or more, the yield is many times increased, and the cost is reduced. At the end of 1941 it sold for about 16 cents a pound, and this might be lowered to ten cents. East-Indian rubber sold at that time for about 22 cents; so guayule seems definitely promising.

Beginning with indigo, chemistry has succeeded in synthesizing many natural products, often so successfully as to replace nature's work. These triumphs usually come in three stages. First, the exact chemical composition and structure of the original would be determined by chemical research. Then methods were developed to duplicate it from cheap and available raw materials. After this would come commercial production on a large enough scale and at low enough cost to permit it to compete with, and perhaps to replace, the natural product, as happened with indigo, and, in more recent times, with the vitamins. For the production of the chemist is chemically identical with the original, not an improvement—its advantage being that it can be made more cheaply and purer.

Such was, at first, the pattern followed by the rubber researchers. Faraday had shown the basic formula of rubber to be C_5H_8 . In 1860 an Englishman, Greville Williams, broke up rubber with heat and obtained a chemical called isoprene. This molecule contains four carbon atoms and five hydrogen atoms in various combinations in a row. Branching off to the side, and attached to one of the carbon atoms, is a "methyl group" made of a carbon combined with three hydrogens. This totals five carbons and eight hydrogens, in accordance with Faraday's formula.

However, this is not rubber. Isoprene is the "monomer," one of the links in the chainlike molecule, or "polymer," of which it is made. Hundreds, or even thousands, of such links are joined together to form the long molecule of rubber. This structure was suggested first by the Frenchman Gustave Bouchardat who, in 1879, actually made a product remotely resembling rubber, with isoprene as a basis.

This chainlike structure of rubber is held responsible for its properties. In unstretched rubber these chains are tangled up in a very irregular fashion. When it stretches, they are, partially at least, straightened out. X-ray studies provide a confirmation of this. A beam of the rays passed through stretched rubber is scattered to form a regular pattern similar to that obtained by passing them through a crystal, where the atoms are arranged in a definite lattice structure. But unstretched rubber shows no such pattern.

When the automobile industry began to assume importance, interest in a possible synthetic rubber was renewed. For example, in 1915, when the Germans found their rubber supply cut off, they turned to a process which had been shelved a few years before. This produced methyl rubber, inferior to natural rubber. Nevertheless a factory with a 150-ton monthly capacity was operated until the armistice. The years following the war saw an effort by British interests to restrict the output of their plantations; this caused a rise in price, and renewed interest in synthesis. When, by 1926, production had begun in earnest in the Netherlands Indies, the laboratory work was dropped, with two exceptions. One was that of the Du Pont Company; the other, very significantly, was that of the I. G. Farbenindustrie in Germany. But still synthetic rubber, in the sense of a test-tube product identical with that from trees, eluded the chemists, and even today has not been achieved.

It began to be recognized that perhaps it need not be achieved—that possibly the exact combination of atoms in rubber from *Hevea* was not necessarily the only one, or even the best. The approach then was to evolve new products which

would also consist of the long chain molecules, or polymers, but which might be made of units entirely different from isoprene. If these had physical properties similar to or better than rubber, little more could be desired.

About this time Father Julius A. Nieuwland, professor of chemistry at the University of Notre Dame, was working, as he had been for most of his professional career, on acetylene, with little thought of rubber. In 1925, before a meeting of chemists at Rochester, he presented a paper describing some of the newly derived compounds which he had made from acetylene. Dr. Elmer Bolton, of the Du Pont laboratories, who was present, saw that some of these might solve his problem of creating synthetic materials such as rubber. The Du Pont group acquired the necessary patent and other rights, and by 1931 at a meeting of the Akron section of the American Chemical Society, they were able to announce success.

Their product which made its debut as "Duprene," is now called Neoprene. Chemically, it is polychloroprene; that is, it consists of a chain of units called chloroprene. This is made up similarly to the isoprene unit, or monomer. It, likewise, has the row of four carbons and five hydrogens, but attached to the side is a chlorine atom, instead of the methyl (CH_3) group. Ordinary rubber contains no chlorin, but in Neoprene it is present to the extent of 40 per cent. Strictly speaking, therefore, it is not synthetic rubber, though that term is now used, even in technical publications, to cover any synthetic compound which has approximately the physical properties of rubber. Occasionally a new word, "elastomer," is used to include rubber and all its man-made substitutes.

Raw materials for Neoprene are coal, limestone and salt, all easily obtainable in the United States. First the coal and limestone are used to make calcium carbide, from which, when water is added, acetylene gas is given off. In the early days of automobiles the headlights burned acetylene, and the gas for them was made in the car, in a generator in which water dripped on calcium carbide. With the advent of efficient battery-

operated electric lamps, acetylene passed out of the automotive picture, so it is curious that, in another way, it seems to be returning.

Father Nieuwland's contribution was a process by which, with the aid of catalysis, acetylene could be converted into a substance called divinylacetylene; but no synthetic rubber could be made from this. However, the process was slightly modified to produce monovinylacetylene, formed by the union of two acetylene molecules. This consists of a row of carbon and hydrogen atoms, almost the same as that to which the methyl group is attached in the unit of ordinary rubber.

When the monovinylacetylene is acted on by hydrochloric acid (which is made from salt), chloroprene is obtained. Then comes the trick of persuading these links to join themselves into the chain. This is done by mixing chloroprene with soap, or some similar agent, and water, to form an emulsion. Normally only a few hours are required to yield the polymer of chloroprene, which is Neoprene.

From then on, the material is handled very much like rubber. It can be vulcanized, with the addition of sulfur, to increase its strength, although this is not necessary. In Neoprene alone among the synthetic rubbers, when it is heated there is a permanent change, similar to that of vulcanization, without the addition of other chemicals. In industrial use, however, it has been found more desirable to add certain other ingredients. The properties of Neoprene can also be varied by stopping the polymerization—the joining together of the links—before it is complete. But a stabilizing material is usually added, even when the full polymerization is reached. Otherwise, the linking may tend to go on too far, or else cross links may form among adjacent molecular chains. This would cause the material to stiffen while it is in storage.

The basis of another type of synthetic rubber, which includes most of those made in Europe and a number from American

factories, is butadiene. Above 23° Fahrenheit this is a gas. The structure of the molecule is similar to those we have met before—a row of carbon and hydrogen atoms. At each end are CH_2 groups, and in the middle are two CH groups, so it consists of four carbon atoms and six hydrogens. As a matter of fact, chloroprene may be thought of as chlorbutadiene—that is, butadiene in which one of the hydrogens has been replaced by chlorin.

In Germany and Russia butadiene is prepared by a method very similar to that used for chloroprene, but using hydrogen instead of hydrochloric acid in the last step. The Russians proceed by chemically breaking up alcohol, made from the fermentation of grain or potatoes. In this country butadiene is made from the cracking of petroleum. In any event, the butadiene must be very pure. Then, with the use of sodium metal as a catalyst, these units, when held for a period of days at a somewhat elevated temperature, link themselves together to form the polymer.¹

The most popular of the German types, developed in the laboratories of the I. G. Farbenindustrie to provide tires for the panzer units, are those known as Buna S and Buna N. Here the butadiene links are alternated with links of another compound—styrene in the case of Buna S and vinyl chloride in Buna N, which is also called perbunan. Chemigum, the synthetic rubber of the Goodyear Tire and Rubber Company, is reported to have a similar constitution, although the exact composition has not been revealed by the manufacturer. Probably Ameripol is similar. This was used by the B. F. Goodrich Company for the first automobile tires of synthetic rubber to be put on the American market.²

¹ This process was used in Russia and also, before 1939, in Germany. Another kind of Russian synthetic, known as Sovprene, is similar to Neoprene, containing chlorin.

² The raw materials come from petroleum, gas and air, so the Goodrich Company jointly organized the Hydrocarbon Chemical and Rubber Company as a subsidiary. They produce their synthetic rubber under the name of Hycar. Dr. Waldo L. Semon has been in charge of this development. Another large oil company that is playing an important part in synthetic rubber development

The clue to a great many of the characteristics of rubber and its relatives is the property known as "saturation." In the chart showing how natural and synthetic rubbers are formed (see Appendix, page 285) it will be noted that there are always four links, or bonds, connecting the carbon to adjacent atoms. Chemists express this by saying that the valence of carbon—that is, the number of other atoms with which it will unite—is four. But in some cases, as the chart shows, there are only three atoms around a carbon atom, and then one of the bonds is shown double.

Such a condition is called "unsaturation"; and when it occurs, the carbon atom is always receptive to another atom of something else, to use up the extra bond. When rubber is vulcanized, the sulfur atom grabs one of these double bonds and becomes attached to a carbon atom. But sulfur has a valency of two, so it grabs two carbons, in separate chains, forming a cross-linkage between them, and giving vulcanized rubber its strength.

The trouble with natural rubber is that there are so many of these unsaturated double bonds. If sulfur is added and added to the point where all double bonds are eliminated, we have vulcanite, or "hard rubber" (from which combs were formerly made), a product by no means suitable for tires, raincoats or rubber bands. So in ordinary practice vulcanization is continued until the product has sufficient strength but is still elastic. This leaves a great many friendly carbon atoms with only three neighbors, and if they cannot get sulfur to unite with, they will take something else, which often turns out to be oxygen from the atmosphere. The effect of oxygen is to weaken the rubber, and that is why tires and other rubber goods deteriorate while standing. The process is speeded by sunlight, and for that reason rubber should be stored as much away from sun and air as possible.

In making butyl rubber, Dr. Frolich and the men working

is the Standard Oil Company of New Jersey. At the Esso Laboratories, operated by the Standard Oil Development Company at Linden, N.J., Dr. Per K. Frolich and his colleagues have produced butyl rubber.

with him found a means of controlling saturation. The isobutylene groups, which form an important part of its molecule, are saturated because they have none of these loose ends. Just sufficient butadienes are put into the chain to give from one to two per cent of the unsaturation found in natural rubber; this will permit enough sulfur to combine to give the necessary strength. Then all the double bonds are gone! Exposing vulcanized butyl rubber to oxygen produces no deterioration. It is also resistant to other chemicals such as concentrated nitric and sulfuric acids, which quickly attack natural rubber.

Rubber, natural or synthetic, can be molded because of its ability to be vulcanized. At first it is soft and can easily be shaped in molds or by other means. Then, while it is in the mold, the vulcanizing process introduces the necessary ties across from chain to chain and gives it strength. As a model, we might think of a fish net made of rubber bands—which would not be very strong. Strength might be added by tying the rubber bands of the mesh together with relatively long parallel pieces of string. This would make the net stronger because the strings would impose a limit and prevent stretching to the breaking point, except with very great force. This corresponds to vulcanized rubber. But if the pieces of string were the same length as the rubber bands, the net would not stretch at all, and then we would have the condition of hard rubber.³

In addition to tires and electrical insulation, there are many other applications for synthetic rubber. Gasoline, fuel oil, kerosene and similar liquids weaken the natural product, but many of the synthetics are highly resistant. These synthetic rubbers, even before the natural-rubber shortage imposed by the war,

³ However, there are a number of compounds classed with synthetic rubber that, lacking double bonds entirely, are completely saturated and cannot be vulcanized; nevertheless they have many uses. One of these is Flamenol, made of units of polyvinyl chloride, which was developed for a heat-resistant electrical insulation by General Electric. Koroseal, made by the B. F. Goodrich Company, is similar; so is Vinylite Q, of the Carbide and Carbon Chemicals Corporation.

were taking their place in refineries, filling stations, and in many parts of the automobile itself, and in airplanes also, where contact with oil would occur. They are used for vibration absorption, and this same property makes them useful for shoe soles and heels. Indeed, for every possible use of rubber a synthetic product will probably serve.

In his American Chemical Society report, Dr. Frolich well summarized the situation in regard to the possibilities of synthetic rubber. He says:

Originally the goal of those working in this field was to synthesize a product that would equal natural rubber in those properties which have contributed to make it one of our most important structural materials. The more recent trend is to synthesize materials closely resembling Nature's product in some respects, while at the same time surpassing it in others. In the light of achievements to date, we are justified in looking forward to the development of a series of synthetics, each one of which will exceed natural rubber in certain properties; in the aggregate, therefore, these products will give us something superior to rubber as we know it today.

The future of synthetic rubber therefore seems promising. Spurred by war needs, supported by government subsidies, large manufacturing plants were put under construction, boosting many fold the production of synthetic rubber over what it was only a short while ago. Approximately 17,000 tons were made in 1941; but plans called for a production of well over 400,000 tons a year in the near future. Yet, although raw materials are cheap and plentiful, perhaps the cost can never be reduced low enough to compete with natural rubber at its pre-war rate of ten cents a pound or less. In our post-war economy, therefore, it is likely that natural rubber, perhaps from Central and South America, and synthetic rubber as well, will both have their places. Tires may be made with a body of natural and a tread of synthetic rubber; and other combinations may be used. But at least we will no longer be at the mercy of a foreign and hostile power in securing such a vital material.

VII. *Chemistry and the Farmer*

From time immemorial the aim of agriculture has been to produce food. As farmers' methods were improved, the aim was to make two blades of grass grow where one grew before. This has had an important economic effect—it has, for instance, been largely responsible for invalidating the fears of Malthus that the world's population would be limited by the food-producing facilities known in his day. (Malthus died in 1834.) Increased efficiency, and the opening, which Malthus did not foresee, of vast new farm lands, finally resulted instead in the absurd situation where farmers in 1934 were paid for the crops they did not plant!

The past decade, however, has seen another and more scientific approach to the problems of agriculture; one which already has had important results. It is not to create more crops but to find more uses for those we have. Like oil wells and mines, farms are now to provide raw material for industry; and to describe this the word "chemurgy" has been coined—the first part from our familiar "chemistry," the second from the Greek "ergon," meaning work. The idea conveyed is "chemistry at work." In 1935 the Farm Chemurgic Council was established, with the backing of a group of prominent scientists as well as representatives of industry and agriculture. Its avowed object is "to advance the industrial use of American farm products through applied science." Since its founding, largely through its meetings, the Council has done much to further this aim, and to give farmers a new outlet for their crops and other products.

Milk forms an excellent example of the possibilities of this chemurgic resolution of the farm problem. With its products worth more than \$3,000,000,000 annually, the dairy industry surpasses the automobile industry and the steel industry in

size. With 25,000,000 cows, worth about \$1,500,000,000, as well as the many millions of dollars invested in farms and equipment, it is truly important. And its value to the farmer is shown by the fact that milk brings the farmers more income than any other single crop.

Of the 50 billion quarts of milk processed annually out of air, water, salt and grass by the nation's cows, about 42.5 per cent is sold as fresh milk or cream. Butter making takes some 41 per cent, and six per cent goes into cheese. For evaporated and condensed milk, 4.5 per cent is required; ice cream takes somewhat more than three per cent, and malted-milk powder and other miscellaneous uses account for the three per cent remaining.

With this apparent 100-per-cent usage, it might seem that there is none left over, but Dr. L. K. Riggs¹ assured his hearers at a recent meeting of the Farm Chemurgic Council that this is fallacious. He said:

When fresh milk goes into a bottle, or into a powdering or condensing process, that's that. The entire quantity is disposed of. But when milk goes to the butter or cheese manufacturer, his main interest is in only one part of that milk—the butterfat. When he runs a hundred quarts of milk through a cream separator, he ends up with roughly four quarts of cream which he can use in his operations, and ninety-six quarts of skim milk which he can't.

Consider that it takes the cream from ten quarts of milk to make a pound of butter; consider too that the country's annual butter production exceeds two billion pounds—and it's easy to see why the skim milk from this one source alone assumes torrential proportions. As a matter of government record, the amount of skim which results from butter, ice cream and bottled cream operations totals twenty-five billion quarts a year. But that's not all. By the time the butter makers get through with their churning process they have about a billion and a third quarts of buttermilk on their hands in addition to the skim milk.

From 3,750,000,000 quarts of milk used to make the year's output of 700,000,000 pounds of cheese, nearly three billion

¹ Director of research of the Kraft Cheese Company, which is a division of National Dairy Products Corporation.

quarts of cheese whey are left. And a billion quarts of casein whey remain after skim milk has been processed to remove the casein. All told, this is 30 billion quarts of liquids left over, containing many products of potential value.

As skim milk comes from the separator spout, stated Dr. Riggs, "it has everything in it that was present in the whole milk, with the exception of the butterfat, Vitamin A, and Vitamin D content. That means the skim carries substantial values of Vitamin B₁ and Vitamin B₂, proteins—especially casein and albumin—lactose and minerals. Buttermilk has much the same constituents as skim milk, while whey is rich in proteins, lactose, minerals and riboflavin (Vitamin B₂). Multiply the elements found in a single quart of these liquids by the thirty billion quarts available—then consider the wide range of industrial uses already found for these substances, and there can be little doubt of the justification for continued research."

At present some six billion quarts, or about a fifth of the total, find a use, mostly for making casein. The chief use of the rest is as food for livestock.

Casein is an important industrial material. For example, it can be made into a plastic which is widely used for buttons, buckles, beads, game counters and the like. This is produced in sheets, rods or disks, which are already hardened, and can be cut or ground to the desired shape. For buttons, however, blanks are formed from the soft mixture of the casein with the plasticizer. Not having been "cured," they can easily be shaped to the form wanted. Then they are put through a formaldehyde bath for hardening. They have the disadvantage of absorbing moisture rather freely; but as they are easily colored, machined, and polished, and are non-inflammable, they have been quite popular, under the trade names of Ameroid and Galorn.

Among its many other industrial uses, casein is made into paint. It can be mixed with nothing more than cold water, yet when applied it gives a permanent coat which is insoluble and can be washed. In some forms, it has been adapted for out-of-door use. Since it is quite opaque, it easily covers and hides

older surfaces, making one coat usually sufficient. Delicate color effects can be obtained with the mixture of proper pigments, and, as it does not yellow with age, these are durable.

The principal uses of casein, however, are for making book-binding and woodworking glue, and as a coating for paper, which, at present, employs more casein than all other applications combined. In a particularly pure form, it is also used in medicine. Though there are plenty of outlets for casein, and there is plenty of skim milk to supply it, the trouble is that it is not in one place but scattered around the country in hundreds of thousands of puddles on dairy farms. One remedy, perhaps, would be to devise a simple machine by which the farmer himself could turn his skim milk into casein. As this takes up considerably less room than the liquid, it would be much easier to ship to plants in a position to put it to work.

A synthetic wool-like fiber from casein is another possibility. A few years ago this was produced in Italy under the name of Lanital. Fibers are spun in an acid bath, and have many properties of wool, but they are not as strong. This weakness is especially evident when they are wet. However, the Bureau of Dairy Industry of the U. S. Department of Agriculture, and commercial groups, such as the Atlantic Research Associates, an affiliate of National Dairy Products Corporation, have done considerable research in the field. Where used in fabrics, the fiber is always mixed with an equal, and often a greater, amount of natural wool.

The casein fiber of the Atlantic Research Associates, marketed under the name of Aralac, has also had a use that savors of magic—it takes rabbits out of men's felt hats. Felt is believed to have been discovered by some unknown primitive shepherd. Probably he took some wool from his sheep and made a little cushion to put in the heels of his shoes. Warmth, moisture and pressure turned this into felt. Today wool felt is largely used for women's hats, while men's hats are made of felt prepared from rabbit fur. But now manufacturers mix casein fiber with the rabbit fur, and find it advantageous in many respects. Since

two or three rabbits are required for an ordinary hat, the use of just a third of casein fiber pulls a rabbit out of each hat so made!

Skim milk is a by-product of the dairy industry, but even after the casein has been removed there is a further by-product—whey, familiar as part of Little Miss Muffet's favorite diet. It is a watery liquid, still containing some important food materials, such as protein and milk sugar. Of the seven per cent of solid matter in whey, about 75 per cent is milk sugar, or lactose. It has been used in a dried, powdered form, for feeding to children and adults who do not otherwise have enough minerals in their diet. This, however, accounts for only a minute proportion of the total; most of the whey produced is either thrown out or fed to the pigs.

Under the direction of Dr. B. H. Webb, the Bureau of Dairy Industry has devised a use of whey in the form of candy, called "Wheyfers." They are something like molasses chips, but with quite a different flavor. Usually they are coated with chocolate, partly for taste, but largely to keep them from absorbing moisture, which they easily do in humid weather. Fudge and caramels can also be made from whey, as Dr. Webb has shown.

With a number of industrial and pharmaceutical uses for the lactose, the lactic acid, and the sodium, calcium, iron, copper and other lactates which can be prepared from whey, this also is potentially an important raw material. If the problem of collecting can be solved, milk may some day be as important in industry as it now is in the business of supplying food to a nation.

Then again there is the soy bean, grown for ages in China, where it has formed a principal part of the diet. In 1804 it was introduced into the United States, but only in the last few decades has it achieved any great importance here—largely through the encouragement of the Ford Motor Company. It

can be grown, in general, in any climate suitable for cotton or corn, and it is fairly simple to cultivate. In recent years two quarts of soy-bean oil for the enamel, and an equal amount in the form of glycerine for the shock absorbers, have gone into every Ford automobile. Not only glycerine and enamel but also explosives, varnishes and paints, soaps and printing inks are products into which the soy bean may enter.

It can be used, too, for plastics; and these are similar to those made from casein, since the main ingredient of the soy bean, like casein, is a protein. However, soy-bean plastics have not yet reached a state of commercial development, largely because of difficulty in molding methods. Several concerns are engaged in research, and as a result of their efforts the high water absorption of these materials, like those from casein, has been reduced. Where formerly the absorption was about two per cent after 25 hours of immersion, it has now been reduced to less than a third of this figure.

Soy-bean fiber has been advanced somewhat further, as we noted in our discussion of "chemical clothes." According to the 1942 *Plastics Catalog*, the average production of an acre of soy bean is about 25 bushels, in which there are some 600 pounds of protein. This in turn contains at least 500 pounds which may be converted into the soy-bean protein fiber. First the oil is extracted, and becomes available for the various other uses. The protein is prepared from the meal that remains, and is dissolved to give a thick, stringy solution, from which the fibers are spun. Following an after-treatment, a white or light-tan fiber is the result, one which "has a very warm, soft feel, natural crimp and a high degree of resilience and flexibility." It does not wet as readily as casein fiber, and is more resistant to the action of mold. Since it can be handled on the machinery used for ordinary cotton and worsted, it may well be an important product in coming years, and find uses in clothing and upholstery, particularly when mixed with wool, rayon or cotton.

Other crops that the farmer grows have possibilities as well. Idaho, for example, is famous as the native state of the "big baked potato," yet, in grading out the big ones, vast amounts of smaller ones, called cull potatoes, are left over. Some can be fed to stock, but this takes only a small proportion and the rest are wasted. However, potatoes contain starch, and starch is most useful industrially in many ways besides the stiffening of collars and shirts.

Starch plays a part in explosives manufacture. At a recent meeting of the Farm Chemurgic Council, R. E. Gale, of the Idaho Power Company, told how one region of his state decided to use the cull potatoes for starch manufacture. Speed was essential, because it was then early summer and the starch production had to be under way in October if the year's crop was to be caught. Priority troubles making it impossible to get new machinery, a beet-sugar factory, then being dismantled some 600 miles away in Utah, was purchased; and the machinery, supplemented with some other parts obtained from the automobile junk yard, was brought to Idaho. Now the starch mill is at work. The big potatoes still are shipped to market, while the smaller ones pay their way as starch.

From zein, a protein present in corn, it may also be possible to make a plastic, though this is still in the very early stages of experimentation. However, corn is an important source of many chemicals used in major industries.

For instance, the Commercial Solvents Corporation, which makes not only the solvents used to carry other chemicals but also many that are themselves vital parts of reactions in industrial chemistry, has cited compounds such as acetone, butanol, methyl (wood) alcohol, ethyl (grain) alcohol, and a number of others which can be produced from corn. Acetone has uses in such varied fields as explosives, the making of viscose, or cellulose acetate fiber, photographic films, and plastics from cellulose nitrate. Butanol is used in lacquers, photographic films,

artificial and patent leathers, to make synthetic resins, and in dry cleaning, to mention only a few. Methyl alcohol has uses such as the manufacture of formaldehyde, dye solvent and anti-freeze; and it is also important in the making of plastics.

All these products can be derived from natural gas and petroleum, but Commercial Solvents largely uses corn as the source. Nearly two bushels of corn are consumed in making the lacquer for a single automobile; the lacquer also is used to make a surface on toys—and locomotives. This one company has a capacity for converting 11,000,000 bushels of corn annually into chemicals. Here is an example of what can be done with an excess of one crop. It is not necessary to destroy the surplus, or to resort to drastic means of restricting its production, when it can be processed in ways so useful to all.

Despite the use of structural iron and steel, wood, the oldest of building materials, maintains its position of importance; a position lately enhanced because of the shortage of metals. But cutting logs into boards is an unavoidably wasteful process, in which many chips and trimmings are left. To get big boards, big trees are needed which yield big logs. But they take time to grow, and smaller boards must be used. That means more joints and greater expense in putting the structure together.

In the past, lumber mills always had great waste burners where chips and other leavings went up in smoke. But in many Southern mills this has been eliminated since William H. Mason found a means of turning these very wastes into a product called Masonite—a building material of great utility. Today Masonite is in some ways superior even to the boards which formed the main output, and from which the smaller bits were “waste.”

The nucleus of the entire process is the so-called Masonite “gun” from which the wood is exploded. Wood chips of suitable moisture content are loaded into guns, which are cylindrical steel vessels of from twelve to twenty-six cubic feet capacity, equipped with a quick

opening hydraulic valve at the bottom. When full the gun is closed and steam admitted to a pressure of 600 pounds; this requires about 30 seconds. The pressure is then quickly raised to 1000 pounds, and held there for approximately one to two seconds, at which point the bottom valve is opened and the entire contents of the gun discharged into a cyclone which separates the fiber from the steam.

This action not only explodes the chips into a mass of finely divided fiber, but also has a definite chemical action on the wood constituents. Less than one minute elapses from the time the gun is loaded with wood chips until the resulting fibers are discharged into the cyclone. The stock is then refined to the desired degree, the wet-lap formed on a special type of board machine, and after being cut into twelve-foot lengths, the wet-laps are conveyed, 20 sheets at a time, into the hydraulic presses. The length of time the board is in the press, and the temperature and pressure to which it is subjected, are determined by the density, thickness and type of board desired. In addition, the gun operation can be varied over a wide range of conditions, which in turn gives rise to a wide variety of exploded material, and makes possible the various types of board products.²

The most densely packed material that can be made from wood in this way is a substance resembling marble, called Benalite. Since it weighs above 90 pounds to the cubic foot, there are practically no voids left between the fibers, so further pressure is unable to compact it more. At the other extreme is Cellufoam, with a density of slightly more than a pound per cubic foot. In between these are a number of others with their own characteristics. Yet they are essentially all wood, for ordinarily no fillers, binders or other molding materials are added.

Wood consists, to the extent of about 50 per cent, of cellulose. This is the principal constituent of paper, which, if the other components of wood are allowed to remain, is weakened. Consequently, paper makers try to remove the non-cellulose constituents. So called "wood sugars," technically "hexosans" and "pentosans," make up about 20 per cent of wood, while the remaining 30 per cent is lignin, the exact composition of which is still an unsolved problem of chemistry.

In making Masonite the lignin remains, and is used. Dr.

² Roger M. Dorland: First Annual Southern Chemurgic Conference, Nashville, Tenn.; June 17, 1941.

Dorland, director of Masonite research, is authority for the statement that it may be considered as the binding material between the wood fibers; that the explosion process separates them, and activates the lignin in some peculiar way, thus enabling it to weld the fibers together again when heat, moisture and pressure are applied. Unlike the "paper type bond," which is strong when dry but becomes weak when wet, this is a "wood type bond," strong both wet and dry.

This process resembles the manufacture of thermosetting plastics, already described. As with the synthetic resins which, once set, cannot be softened again by any simple process, the rebonding of the lignin is not reversible by any normal treatment. That is, a piece of the material cannot be defibered and then put together again as effectively as before. It was a study of the Masonite process, and the realization that the lignin actually passes through a plastic state, that led to an investigation of the extent to which this quality could be developed. The result was the hard, dense material called Benalite, made normally under 1500 pounds pressure per square inch.

Even in making Masonite, the 20 per cent of wood substance called "hemi-celluloses," which are neither cellulose nor lignin, are not wanted. As they are soluble in water, the obvious method of removal is to flush the fiber with large quantities of water. While this removes them, the resulting solution is too dilute to make practicable any use of the chemicals it contains. However, an extracting method has been devised which removes them in a more concentrated form. The "sugars" obtained may be converted into acetic acid, formic acid, wood alcohol, butanol, acetones, glycerine, and other chemicals important in industry. And even the lignin, which is not wasted in the Masonite process, but is lost in the paper mills, also can be salvaged, for it is a source of vanillin, the active principle of vanilla extract. Since the supply of natural vanillin was cut off, this has almost entirely replaced the bean extract. The next plate of vanilla ice cream you eat may have been flavored with a product obtained from an odorous and dirty liquid which was

once the waste from a pulp mill. The "magic" of chemistry has converted it to a product which is even purer than the natural extract! ³

In many parts of the South pine grows luxuriantly but the land is not very suitable for other crops; the South needs new industries, and the United States should be independent of imports as far as possible. Considerations such as these have resulted in an increasingly important paper industry along the southeastern seaboard, largely as a result of the researches of Dr. Charles H. Herty, professor of chemistry at the University of North Carolina until his death in 1938.

Paper had been made from southern pine, especially Kraft paper for wrapping, long before Herty's investigations. For such paper, color is not important. Some was made into white paper and, though the bleaching process increased the cost, the original material was so cheap that the product could still compete in the open market. Herty, then, did not invent a new process of paper making. Only slight changes in standard methods, used in other places to make news print from woods such as spruce, were needed to make it of equal quality from pine. His real contribution was stated thus by Dr. Harrison E. Howe at the time of Herty's death: ⁴

He succeeded in demonstrating the usefulness of southern woods, notably pine, as a pulpwood, and the effectiveness of the sulfite process for treating it. Many of his friends believed that he had developed

³ Oxalic acid, useful in making celluloid, rayon, leather, textiles and other vital materials, is another chemical that may be obtained from wood. Dr. Donald F. Othmer, head of the chemical engineering department of the Polytechnic Institute of Brooklyn, described an inexpensive process of making it from sawdust at a recent American Chemical Society meeting. He said that 100 pounds of dry sawdust, of which some 8,000,000 tons a year are burned or wasted, will produce about \$8.00 worth of chemicals; not only oxalic acid, but also acetic and formic acids and wood alcohol. Only lye, lime and sulfuric acid, all cheap and readily available, are needed. Out of 100 pounds of dry sawdust can be made 50 pounds of oxalic acid, 14 pounds of acetic acid, and four pounds each of formic acid and wood alcohol. These, in normal times, would sell for \$7.94.

⁴ *Industrial and Engineering Chemistry*. September, 1938: p. 963.

an essentially new process and by publicizing that belief created ill will for the project among those who knew all the facts. Dr. Herty had demonstrated that by using young trees many difficulties could be avoided, but he developed no really new process nor did he ever claim to have done so. He was able as a crusader to call attention again to the potential resources of the southland and to ways in which rapidly growing trees could be utilized.

Certain species of these pines require less than a score of years from the seed to the full growth; and if two or three adult trees to the acre are left standing, the ground is reseeded without human attention. In a single acre as many as 40,000 seedlings may spring up. Obviously, all cannot grow, and they must be thinned to about 400 per acre during the first few years. However, many of those that are to be removed may be left until they have grown large enough for pulp. Those remaining after the first decade are large enough to yield turpentine for another eight to ten years. Then they may be cut for timber. In this way, three different crops are obtained from the same planting of trees. However, because of difficulties in synchronizing their activities with others, the pulp makers have been rather loath to put such a system into effect on a widespread scale, and prefer instead to harvest all their young trees when they will give the maximum yield.

Cotton, of course, is the great crop of the South. Here also chemurgy is paving the way, both to improving old uses of cotton, so that it can compete more successfully with newer products, and to developing new uses. In 1937 a group of private individuals in Tennessee founded the Cotton Research Foundation. Most of the Foundation's work is done by a group working at the Mellon Institute in Pittsburgh, admirably suited to take on such a project.

All the parts of the cotton plant are being studied, even the hulls and the stalks, which were formerly wasted. The bran obtained from the hulls can be made into an economical and effective compound for sweeping. The stalks can be used for making wallboard and similar products, though the commercial

possibilities of this process remain to be explored fully. Cotton linters (the fuzzy stuff that sticks to the cottonseed after it has gone through the cotton gin, and the longer fibers, making up the lint, have been removed), has long been used for stuffing upholstery. During World War I it found wide application chemically in the making of nitrocellulose explosives. Following the war, uses for it were developed in the rayon and plastics industries, though improved types of wood pulp have provided keen competition. The Foundation is studying the properties of the linters with a view toward restoring this use.

Cotton cloth itself, of course, is being studied. For example, cotton sacks as containers have been replaced in recent years by paper bags for many products. Largely this has been on account of the greater resistance of paper to penetration by dirt and water. Part of the research has therefore been directed to improve resistance of cotton and to give it the advantages both of paper and cloth.

Peanuts form a crop that is grown in all of the Southern states; and these "goobers" are mostly used as food for man and beast. From the shelled nuts, oil (about 35 per cent) and meal (65 per cent) are obtained. The peanut meal makes a feed of high protein content for livestock. But, although these are the main purposes for which the peanut is utilized, there are chemurgic possibilities, many of which have been developed by the Negro chemist, Dr. George W. Carver. For instance, the oil is used in soaps, while the peanut itself can probably enter into plastics in much the same manner as the soy or coffee bean. From peanut shells has been made a heat insulating material nearly equal to cork in efficiency yet, on large-scale production, costing about 35 per cent less. And also from the peanut can be made breakfast food, ice-cream powder, inks, dyes, cosmetics and a flour containing a high percentage of protein.

Other nuts have important chemurgic possibilities, and in many cases may prove useful substitutes for raw materials that had been imported before the war. English walnuts are exten-

sively cultivated in the United States, and promise the possibility of 100-per-cent utilization. The meat contains about 65 per cent of oil, which can be pressed out either hot or cold. If cold, the oil is pale and can be used in food, while the hot-pressed oil is useful in soaps and paint. Artists' colors have long been mixed with walnut oil, particularly in Europe, where it has been prepared for many years. Recently production has started in some of the shelling plants on the Pacific coast.

A fine flour made from ground walnut shells is valuable as a base for insecticides, carrying the poisonous principles without loss of potency until they are applied. Plastics, fire brick and dynamite are still other applications for this flour. And almonds, pecans and filberts too have many uses, other than as a delicious food. At the Georgia School of Technology pecan oil was mixed with white wax, borax, water and perfume to make a fine grade of cold cream; while pecan meal, made from the kernels after the oil has been extracted, can be blended with wheat flour in baking. So nuts may eventually form another outlet for the agricultural energies not only of the South, but of other parts of the country as well.

6

As has been remarked, we often hear estimates of the future duration of our natural supplies of coal and oil, and, while many pessimistic views of the past have been proven wrong, there is no doubt that those resources are limited; that they are being used in a time far shorter than the natural processes that made them. But even here farm chemurgy may some day help out, for researches by Dr. Ernst Berl, at the Carnegie Institute of Technology in Pittsburgh, show the possibility of converting any form of cellulose, such as hay, sugar cane or cotton, into coal and oil. These experiments must be carried much farther before they reach commercial practicability, but that time is in sight. And this will help to realize the prophecy made at the

84 SCIENCE REMAKES OUR WORLD

First Farm Chemurgic Conference, in May, 1935, at Dearborn, Michigan, by Henry Ford, who said:

I foresee the time when industry shall no longer denude the forests which required generations to mature, nor use up the mines which were ages in the making, but shall draw its material largely from the annual produce of the fields. I am convinced that we shall be able to get out of yearly crops most of the basic materials which we now get from forest and mine. The time is coming when we shall grow most of an automobile. The time is coming when the farmer in addition to feeding the nation will become the supplier of the materials used in industry.

VIII. *Chemicals for Cures*

On the fateful Sunday morning of December 7, 1941, the Japanese may have found us unprepared in many ways. But this cannot be said for the medical forces of the U. S. Army in Hawaii. Many months before, under the direction of Colonel Edgar L. King, surgeon-in-charge, the medical units of the Army and Navy had been organized to meet the necessity that finally arose. Immediately after the attack two leading medical men from the mainland, Dr. Perrin H. Long of the Johns Hopkins Medical School and Dr. I. S. Ravdin, Harrison Professor of Surgery in the University of Pennsylvania Medical School, flew out to Hawaii to study conditions. On his return, Dr. Ravdin reported that they "both felt that we were witnessing the inauguration of a new era in military medicine. It has been repeatedly said by great generals of the past that an army is no better than its surgeons. If the experience in Honolulu is to be taken as an expression of the type of medical service our armed forces are to receive, we can be sure that in the end victory will be ours."

During World War I, more than three-fourths of the men who sustained abdominal wounds died as a result of infection; but infection was almost completely absent following the Pearl Harbor attack. There were a few amputations required, where limbs had actually been hit by shell or bomb fragments, but none because of infections. Yet during 1914-1918 at one hospital 47 per cent of the amputations were caused by infections of gas gangrene alone. In December, 1941, wounds healed quickly and cleanly. Even though their injuries would undoubtedly have been fatal in an earlier period, the men recovered rapidly, and were soon anxious and able to join the fight once more.

In England, following Dunkirk, comparable experiences had been reported. For example, one group of 266 wounded men showed no infections from tetanus or gangrene, no fatalities, and only one amputation, resulting from extensive injuries which had caused severe bleeding. By a sort of ironic justice, the developments that made possible this record had their beginning in Germany, though medical laboratories in the United States, Great Britain and France played no small part in giving them their effectiveness.

In 1908 an Austrian student named Gelmo discovered a compound which was given the name "sulfanilamide"; and this he described in the thesis he submitted to the University of Vienna to qualify for his doctor's degree. However, neither he nor anyone else at the time could think of any uses for it, though the following year chemists of the I. G. Farbenindustrie, the German dye trust, did try it in an effort to make dyes more fast. In 1919 two German doctors noticed that it killed bacteria, but they made no further study of its effects.¹

By 1933 the Germans had a drug—really a red dye—called "streptozon," which had been developed by Gerhard Domagk, the director of the Elberfeld Research Laboratory of the Bayer Company, one of the units of I. G. Farben. Streptozon cured mice that had been inoculated with virulent streptococci. Probably its first application to a human subject came in 1933, when it saved a ten-months-old boy in Düsseldorf from death by blood poisoning. Since this infection had been caused by another germ, the staphylococcus, instead of the streptococcus, "streptozon" no longer seemed appropriate and the name "prontosil" was applied to that drug. In 1935 Dr. Domagk published a paper in which he presented convincing evidence of the value of his discovery in combatting infection.

¹ Such varied attempts at application of a compound are not unusual. It was in 1904 that Dr. Paul Ehrlich and his Japanese associate Dr. Kyoshi Shiga had found that a mouse infected with the one-celled animal, trypanosome, could be cured through the use of a certain red dye. From these researches came salvarsan, which proved a potent cure for syphilis, since, without killing the victim of the disease—it destroyed the spirochaete that caused it—a process until then impracticable.

His results were quickly confirmed as excited medical research men in various countries began to study them. A group of workers in France demonstrated that even better than the dye itself was a colorless component. This turned out to be the same sulfanilamide that Gelmo had first isolated in 1908. But even before this was done, doctors had started to take advantage of prontosil, and it gained wide publicity in the United States when it was used effectively on Franklin D. Roosevelt, Jr., for a streptococccic infection of the throat. In 1939 Dr. Domagk was awarded the Nobel Prize in Medicine; but his government would not allow him to accept it.

2

Dr. Long of the Johns Hopkins, one of the two physicians who later made the trip to Honolulu, was mainly responsible for the introduction of sulfanilamide in the United States. One of its first sensational successes was in 1936 when a twelve-year-old boy in a Washington hospital was suffering from a most virulent type of meningitis. This is an inflammation of the meninges, the membranes of the brain and spinal cord. One deadly form is caused by the hemolytic streptococcus; and of the many cases that up to then had been treated at the Johns Hopkins, only one had recovered—the death rate was higher than 99 per cent. Yet this was the type from which the boy was suffering.

Two days before Christmas he was given sulfanilamide—two days after Christmas he was showing definite signs of recovery. By mid-January he was well! And since then the death rate from this dread disease has been reduced to less than fifty per cent.

A dramatic demonstration of what sulfanilamide can do for wounds came in 1938 when fire in a Minnesota hotel resulted in fifteen deaths. Two men jumped, breaking their legs and sustaining compound fractures—the kind in which there is a wound with an opening from the break to the surface of the

skin. Physicians treating these men sprinkled powdered sulfanilamide into the open wounds, and they healed without any infection, though previously perhaps a quarter of all compound fractures had become infected. Since then, this treatment has been routine in compound fractures; and as a result infection has become almost unknown.

Today sulfanilamide, still widely used, is supplemented with three other "sulfa" drugs closely related to it. These are sulfapyridine, sulfathiazole and sulfadiazine. A fifth, sulfaguanidine, has also proven of value for certain diseases, notably bacterial infections of the intestines, where it is absorbed slowly, after being taken through the mouth, and remains more concentrated than others, which quickly enter the walls of the intestine and the blood supply of the body.

With the success of sulfanilamide in some diseases demonstrated, it was soon tried on a variety of others, and, while some yielded to it, others did not seem to be affected. Pneumonia was one in which the results were disappointing, so researches were made to find some compound that would do for the pneumococcus what sulfanilamide did for the streptococcus. Yet, as with all these chemicals that cure, it had to be relatively non-poisonous to the body itself.

In May, 1938, a British scientist, L. E. H. Whitby, reported that he had found the desired drug in one of many compounds prepared in the chemical research laboratories of May and Baker, Ltd., a large English pharmaceutical house. Referred to at first by its laboratory serial number, "M. and B. 693," it was later called sulfapyridine, rather than its full chemical name of 2-sulfanilyl aminopyridine. Whitby's results had been obtained with pneumococcal infections in mice; but soon after they were announced two other English physicians, Drs. G. M. Evans and W. F. Gaisford, reported that it had proven effective in clinical studies of human patients. They gave sulfapyridine to approximately every other pneumonia patient admitted to a hospital, until they had had two hundred cases. Of these, one hundred

had the best routine treatment up to that time. The others received the new drug. Of the first group, 27 died, but only 8 died among those who received sulfapyridine.

Other medical men tried it and reported results, in some cases, even more striking. By the autumn of 1938 Merck and Company had introduced the drug in the United States, and during the following winter some 18,000 cases were treated. Of 3,005 cases during that season on which detailed analyses were made, only six per cent were fatal; a far better record than could have been achieved earlier.

Sulfanilamide, in the famous Düsseldorf case in 1933, had been used for fighting staphylococcus, which is the common cause of such ills as boils and other infections that are accompanied by the formation of pus. However, in the United States sulfathiazole was developed, and it proved much more effective against this germ. The latest member of the family, sulfadiazine, is also of American origin. It appeared in 1940; and clinical studies have indicated that, for a majority of the uses in which the sulfa drugs have value, sulfadiazine is just as effective, and less poisonous to the patient than the others.

Various ways are used for administering the sulfa drugs. Ordinarily they are given in the usual manner, by the mouth. Then the drug goes through the intestines, where it is absorbed, and enters the blood stream. But sometimes this may not be quick enough, especially in treating war cases. Dusting the powdered drug on the wound itself gets it to many of the germs, but hypodermic injection is sometimes desirable. One method that has been suggested is with another chemical, closely related to sulfanilamide, which can be prepared in a solution in water which has just about the same degree of acidity as the blood. Carried to the liver and the kidneys, it breaks down to give sulfanilamide, which then can do its work. When a patient is very ill, also, the drug may be given through the rectum.

For a few hours the concentration of the drug in the blood rises, but then it goes down, and most is excreted through the

kidneys. To keep it constantly acting, therefore, it is necessary to continue giving the drug at four-hour intervals, day and night, if the greatest effect is to be obtained.

In wounds, the sulfa drugs must be in contact with the germs. Therefore dead flesh must be cut away so that it will not interfere. The drugs seem to interfere in some way with the life processes of the bacteria, perhaps lowering their rate of reproduction; and then the phagocytes—the white corpuscles of the blood—have more opportunity of devouring them.

Of course, sulfa drugs are no panacea—no such universal remedy has yet been discovered. The victims of some diseases, notably tuberculosis, infantile paralysis, influenza and the common cold, have shown little or no improvement when treated with them. Even diseases for which the sulfa drugs are effective are not conquered one hundred per cent; sometimes strains of a species of bacterium which is ordinarily destroyed develop resistance, even during the course of treatment. Then, unless it fortunately turns out that the germ is still sensitive to one of the other related drugs, the treatment may have to be abandoned and the older methods used. That is the reason, for instance, why serum for treating pneumonia is still used occasionally, sometimes in conjunction with the sulfa drugs, where a double-barrelled assault on the pneumococcus is required.

Though in general sulfa drugs are much more harmful to the germs than they are to the patients, some people show abnormal sensitivity to them, and for that reason it is important that they be given by physicians, not used for self-medication. To protect against this, in most states, laws prohibit druggists from selling them for human use except on a doctor's prescription.

Even doctors have to take precautions with the sulfa group. They are advised, for instance, against discontinuing the drugs too soon. In the case of pneumonia the temperature usually falls to normal in 18 to 48 hours, and the pulse rate recedes soon after that. Other conditions connected with the disease may also disappear quickly with treatment, the response being so dramatic that all danger may soon seem past. Yet to discontinue

the sulfa drug at this point may well result in a relapse. Authorities therefore advise that the treatment continue until the patient is completely convalescent and all signs of pneumonia are gone.

Discovery of the sulfa drugs and their therapeutic effect has, without doubt, been one of the great advances in medical science. But even more important than the curbing of the diseases they have already helped to conquer is the new technique that has been introduced into the healing art. Medical laboratories throughout the world are actively at work following these leads. Many of them will be blind alleys, some will lead to good results; while a very few may even prove more valuable than the ones we already have, with the consequence that human suffering will be further relieved.

IX. *Vitamins*

An ancient Chinese physician, the Crusaders, the British Navy and modern American pharmaceutical laboratories; these are a few of the characters in the fascinating story of the vitamins, those substances in our diet whose workings are not yet fully understood, but of which we now know enough to put them to effective use. With vitamins can be eliminated age-old diseases which occur when they are lacking.

About 2700 b. c. the Chinese physician, Hwangti, described the disease we call beriberi. There is soreness and sensitiveness above certain nerves, numbness of the parts which they supply, then paralysis and swelling of the tissues. Listlessness of behavior and weakness of the heart result; then comes heart failure and death.

The famous Greek physician, Hippocrates, also enters our story, for around 400 b. c. he gave the first known account of the disease which modern medicine calls scurvy. Civilians in cities under siege, seamen on long voyages, soldiers away from home for many months, subsisting on the food supplies they brought with them, suffered from it. It struck the Crusaders on their pilgrimages to the Holy Land. They would develop a sallow complexion, feel tired and breathless. Bones were affected, and there was increased pain and tenderness of the body. Teeth, rapidly decaying, loosened and even dropped out, gums bled easily. Then might come hemorrhages in other parts of the body, and finally death.

Fortunately for the British, in the days when their sailors on naval and merchant vessels were helping to build the Empire, a remedy was found. Though they had not the slightest conception of why the results were obtained, it was discovered that feeding the men fresh citrus fruits greatly lessened their

susceptibility to scurvy. English ships carried limes for this purpose: thus the British sailor, and then Britons in general, received the appellation of "lime-juicer."

Rickets is another disease in the vitamin story. First described in 1650, it undoubtedly occurred earlier. Children shown in fifteenth- and sixteenth-century German paintings sometimes display what is, to the modern medical man, an obviously rachitic appearance. Young children and infants are especially subject to it; bones are softened, joints enlarged, there may be bowlegs, and a poor deposition of lime and phosphorus in the teeth and bones.

Then also there is pellagra which, like the corn or maize with which it seems to be connected, is a product of the New World. About 1600 it was observed among the American Indians, and also among Italian peasants who had used maize as a food. The skin on their hands, neck and feet would become dark and scaly, and later would redden. The alimentary tract became irritated, and there were also nervous and mental symptoms.

The use of limes in preventing scurvy had indicated some connection of that disease with diet, and probably, even in past centuries, some clever doctors may have suspected that a person's food had something to do with the other ills. Then, in 1881, a Swiss physiologist at Basle, N. Lunin, found as a result of experiments that a diet containing proper proportions of the then known food elements—sugars, fats, proteins and minerals—was by itself unable to support life. He concluded that milk, for example, "must therefore contain, besides these known principles, small quantities of unknown substances essential to life."

In 1905, Pekelharing, in the Netherlands, reached a still clearer conception of the nature of vitamins when he found "that there is a still unknown substance in milk which even in very small quantities is of paramount importance in nutrition. If this substance is absent, the organism loses the power properly to assimilate the well-known principal parts of food, the

appetite is lost and, with apparent abundance, the animals die of want. Undoubtedly this substance occurs not only in milk but in all sorts of foodstuffs, both of vegetable and animal origin."

Not one but many substances which answer this description have been found in our foods. Casimir Funk, Polish biochemist then at the Lister Institute in London (he later came to the United States) published a paper in 1911 in which he suggested they be called "vitamines." This name came from "vita," or "life," and the chemical term "amine," the name of a class of compounds to which, he thought, they belonged. About eight years later the final "e" was dropped and since then "vitamin" has been commonly used.

In order to control beriberi in their East Indian possessions, the Netherlands had sent out Christian Eijkman to study it. It was in 1897 that he concluded that the disease resulted from a continual diet of polished rice; and four years later his successor, Gerritt Grijns, showed that it was not from any poison which the rice contained. Rather was it caused by something the rice did not contain—something essential in the discarded brown outer layer (the cortex), removed when the rice was polished. If the people were fed brown rice instead, they did not get beriberi, and even patients who had it were cured when they ate the unpolished grains.

By 1914 experiments with rats had demonstrated that butter contained a substance which aided their growth. It was "fat-soluble"; that is, it would dissolve in fats or liquids, like ether and alcohol, in which fats are soluble. This substance is now called Vitamin A. But in the milk sugar which was included in the rat's diet, there was a second necessary ingredient, and this would dissolve in water. It turned out to be the same thing that prevents beriberi, and it was called Vitamin B. Then, it gradually became clear, many foods, such as citrus fruits, asparagus, strawberries and tomatoes, contain still another element which, also water-soluble, is responsible for the prevention of scurvy. In 1919 this was designated Vitamin C.

After this, the study of vitamins rapidly became more and more complicated. For instance, by 1925 it had been established that the old fat-soluble Vitamin A was double. Often it also contained a second fat-soluble vitamin. This proved to be the one which prevents rickets, and to it the letter D was assigned.

Similarly, it was discovered, the B vitamin also had a multiple character. One substance, destroyed by heat, is the one preventing beriberi. But in addition to this "thermolabile" (unstable to heat) material there were several others which were thermostable (resistant to heat). Included among these was the one which prevents pellagra in man and a disease called "blacktongue" in dogs.

American biochemists decided, in 1929, that the term Vitamin B should be retained for the component which heat destroyed, and to call the heat-resistant factor Vitamin G. But British scientists had other ideas. They preferred to retain Vitamin B for the entire group; then to distinguish the two known components as B₁ and B₂, a practice later accepted by many Americans. But, though B₁ has retained its identity as thiamin, the original British B₂ has now been shown to be a mixture of several substances.

First there comes one which aids the growth of rats and is called Vitamin B₂, or riboflavin. Then there is the substance that prevents pellagra in man and blacktongue in dogs. In 1938 Dr. Conrad A. Elvehjem, at the University of Wisconsin, demonstrated that this was nothing but a previously well-known chemical compound, nicotinic acid. Then there is a part of the heat-destroyed fraction of the original Vitamin B which prevents certain forms of dermatitis in rats. Chemically known as pyridoxin, this is also designated as Vitamin B₆.

Several other components have also been found in the B₂ combination. There is pantothenic acid, discovered by Dr. Roger J. Williams of the University of Texas. Its lack, under some conditions, seems to turn gray the hair of black rats. There is the substance sometimes referred to as "biotin," sometimes as

Vitamin H. Found in yeast, liver and many plant and animal tissues, it meets the rules for admission to the B group. That is, it is found in yeast, liver and cereal products; it is water-soluble, biologically active in small quantities, and its absence in the diet produces a deficiency condition.

Speaking before a meeting of the Chicago section of the American Chemical Society, Dr. Elvehjem gave his hearers some idea of the experimental difficulties in identifying and synthesizing the vitamins, especially those of the B complex, when he said:

The number of Vitamin B compounds left to be identified depends largely on the kind of animals used for experimental work. If we should use a cow or a sheep we might conclude that there are no B vitamins, since the evidence is accumulating to show that the bacteria in the rumen of these animals synthesize the known B vitamins.

For example, the rumen contents of a cow may contain sixty times as much riboflavin as the feed which the cow consumes. The rat does not need nicotinic acid preformed in its diet, but the dog must be supplied with all the known members. Apparently the variation in the requirements of different species depends on the ability of the intestinal flora to synthesize the individual vitamins. Since the human has perhaps the least ability to perform such synthesis, it is essential that we continue our search.

Experiments in which rats are fed with six of the factors of Vitamin B indicate that there are other factors. If we turn to dogs, the evidence is much more clear cut.

When puppies, he explained, are put on a synthetic diet, supplemented with Vitamin B₁, riboflavin, nicotinic acid, Vitamin B₆ and pantothenic acid, they grow for a time, then their growth stops. But then, if they are fed a two-per-cent liver extract, growth is resumed. The liver extract can be treated so as to remove, or at least to destroy, the pantothenic acid, and this still has a beneficial effect on growth, owing to an unknown "factor W." But continued feeding, either of this factor or of pure pantothenic acid separately, results in a failure of the dog to grow. When the original liver extract is given again, the dog's normal growth is restored.

The vitamin with which, perhaps, most people feel concerned is B₁—thiamin. At the time the American Chemical Society presented him with the Willard Gibbs Medal for his researches on this vitamin, Dr. Robert R. Williams described it as "outstanding with respect to the apparent universality of its function in living cells and the degree of dependence of the cells upon an adequate supply of it. The lack of no other accessory substance," he stated, "leads to so early, so profound and so universal a disaster, according to our present evidence."

Sometimes termed the "morale vitamin," this is the one that is added, along with others, to "enriched" bread. The first enriched bread was introduced in England; then, in 1941, American bakers began its production.

This might even be called the original vitamin, for it was the one Funk was studying when he proposed the name for the class. He tried to isolate it, and secured a crystalline substance capable of curing polyneuritis in pigeons. But the scientist now most closely identified with Vitamin B₁ is Dr. Williams. Evidently vitamin research is a family trait, for he is the older brother of the Dr. Roger J. Williams who discovered pantothenic acid.

In 1908 Dr. Robert Williams went to the Philippines and became a research chemist with the Bureau of Science in Manila, where he worked with Captain Edward B. Vedder of the U. S. Army Medical Corps. Beriberi was prevalent among the native troops, the Philippine Scouts, so the Army felt concerned. Dr. Williams and Captain Vedder knew that rice polishings could cure beriberi in infants, and so they attempted to concentrate from this source the beneficial principle. Even before Funk's paper had reached them they succeeded in determining some of the characteristics of the substance. For example, they found that it could pass through a membrane of parchment, that it was absorbed by charcoal and that a chemical called phosphotungstic acid could precipitate it out of solution.

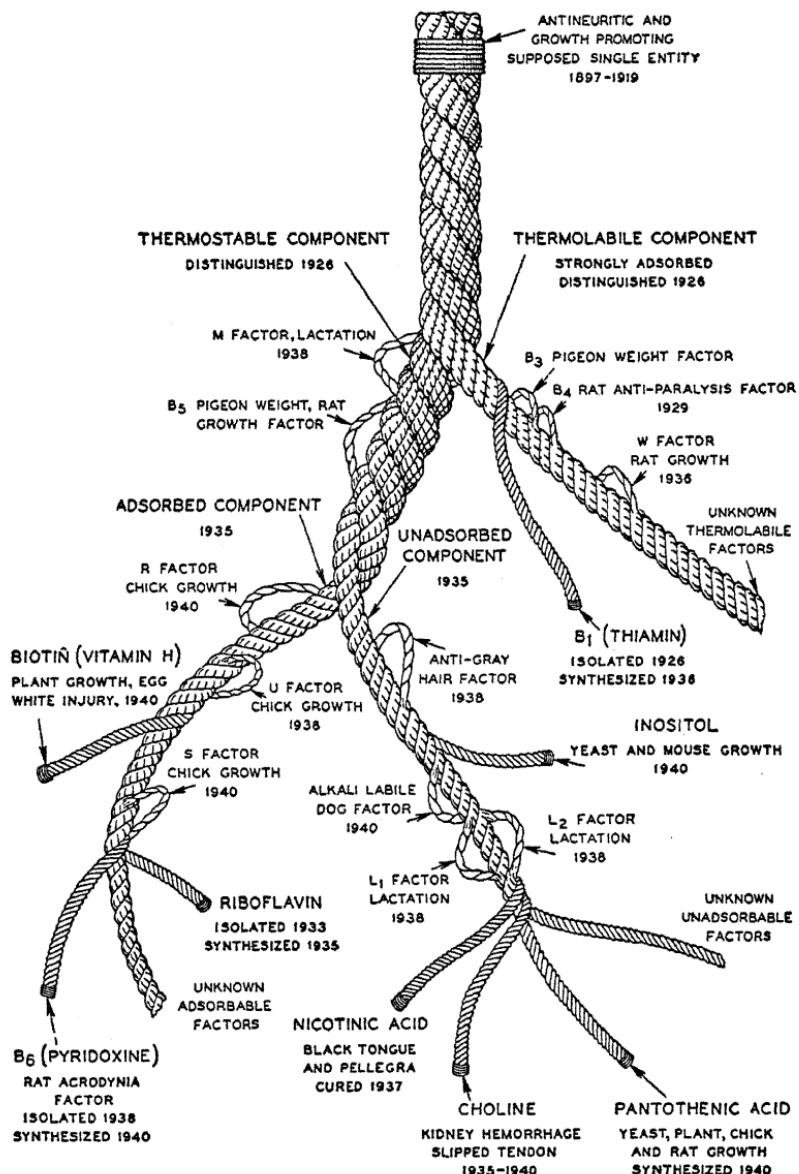
Dr. Williams returned to the United States in 1915, and in 1925 he became chemical director of the Bell Telephone Laboratories in New York; but his interest in vitamin study had continued. In 1926, in the same Java laboratory in which Eijkman's original discovery had been made, B. C. P. Jansen and W. F. Donath announced their success in isolating this vitamin for the first time.

Their technique was most delicate, and no one was able to duplicate their results for a number of years. Dr. Williams, meanwhile, was continuously at work on the problem. He improved the method, and in 1934 he and his associates were able to produce about five grams—a little less than a fifth of an ounce—from a ton of rice polishings. This was several times as good a yield as had previously been obtained; and Merck and Company, at Rahway, N. J., began to produce the natural vitamin commercially. This in turn gave Dr. Williams a plentiful supply of the pure vitamin for a study of how the atoms were put together. Not until the internal architecture of a compound is determined can the chemist put other atoms together in the same fashion and duplicate it synthetically.

It was in January, 1935, that Dr. Williams announced, provisionally, a structural formula for Vitamin B₁. This involved a complex arrangement of carbon, hydrogen, nitrogen, oxygen, chlorine and sulfur. In the summer of 1936 he cleared up the last details of its structure and made the vitamin by synthesis. The isolation work was accomplished in the laboratories of Columbia University, supported with funds from the Carnegie Corporation. The latter part of the structural study, as well as the final synthesis, was carried out under Dr. Williams' direction in the Merck laboratories. As a result, that company and other manufacturing chemists soon afterwards began the commercial manufacture of Vitamin B₁ in the form of thiamin hydrochloride, which can now be secured at any drug store.

Beriberi, fortunately, is a rare disease in the United States and Canada, but even here, as in some of the other supposedly "best-fed" nations, there has been a marked Vitamin B₁ de-

VITAMIN B IN YEAST, RICE POLISH, LIVER ETC.



Like the unraveling of a rope is the untangling of the Vitamin B complex. This ingenious diagram, prepared by Dr. Robert R. Williams, shows that part of the rope remains, from which scientists may isolate future threads.

ficiency. This is blamed on modern methods of preparing food. Just as the polishing of rice eliminated the vitamin, so does the milling of wheat in making white flour have a similar effect. Dr. G. R. Cowgill has found that a diet provided in London by the Poor Law in 1838 actually gave twice as much B₁ as did the diet of the two highest income groups of that city in 1937.

Proof, if it were needed, of the desirability of plenty of Vitamin B₁ in the human diet was provided by Dr. Russell M. Wilder of the Mayo Clinic. A group of subjects, all in good health, were fed a diet adequate in every way—except that it was deficient in B₁. Soon they developed mental and physical fatigue, moodiness, sluggishness, fear and indifference. Another group, receiving a diet which included an amount of the vitamin considered normal, practically equaling the standard set up by the League of Nations Technical Commission, remained in good health. Then he gave this group still larger amounts. Their capacity for work nearly doubled and their alertness was noticeably increased.

Dr. William H. Sebrell, Jr., another vitamin authority, and a member of the U. S. Public Health Service, summarized the conditions existing at the end of 1940 when he told a meeting of the Millers National Federation:

We have been inclined to think that the American public was a well-fed public. As a matter of fact, as data accumulate, we are more and more convinced that it is a poorly fed public, and we now have a lot of information to bear that out. Dietary surveys which have been conducted by the Department of Agriculture, widely conducted in the past several years, indicate very clearly that in the neighborhood of one-third of our entire population are receiving diets which, according to modern standards of nutrition, are definitely inadequate. Those diets are so poor that, while they supply enough calories—and of course all our population, speaking in general terms, get enough calories—they are deficient in minerals and vitamins to such an extent that we see widespread symptoms of them. All groups are affected—it is by no means confined to the low economic groups.

In the whole wheat grain there are ample proportions not only of Vitamin B₁ but also other members of the B complex,

as well as iron and phosphorus, minerals also needed by the body. In whole-wheat flour, and the bread made from it, they are still present, but many of us have come to prefer white bread. Present-day milling methods have been devised on that basis, and flour is made from the very parts of the wheat which contain the smallest percentages of the B vitamins and of the original mineral content.

If everyone would start eating whole-wheat instead of white bread, they would have an ample supply of the grain vitamins. This can hardly be achieved, so the millers and bakers of the nation, following recommendations of the Committee on Foods and Nutrition of the National Research Council, are producing "enriched" flour and bread. Small amounts of pure thiamin, nicotinic acid and iron salts are added to the flour; and also, perhaps, as optional ingredients, riboflavin, calcium and Vitamin D. Bread so enriched looks and tastes no different from that to which we are accustomed, but nutritionists believe that its widespread use will be highly beneficial.¹

In addition to all the vitamins thus far mentioned there are still others, some of which are quite well recognized, while others are suggested by certain experimental data. In the former class are Vitamins E and K. E, known as the anti-sterility vitamin, is chemically alpha-tocopherol; it is made synthetically and is available commercially. It is, fortunately, so widespread in natural foods, and so stable to ordinary methods of cooking, that experimenters have found it difficult to produce a deficiency in the human diet. Studies on rats and mice, however, indicate that such symptoms as sterility and degenerative diseases of the nervous system may result from its absence. Vita-

¹ As already remarked, such bread had been adopted even earlier in England, by vote of Parliament. "M. F. Flour" (Ministry of Foods flour) corrected dietary deficiencies which were especially dangerous in times of stress. Then, if ever, the people needed all possible resistance and stamina. M. F. Flour does not, however, contain as much Vitamin B₁ as the minimum now fixed for the United States, and calcium is a standard, not an optional, part.

min K is a complicated organic compound, also prepared synthetically, which plays a part in the production of a substance called prothrombin in the body and makes possible normal clotting of the blood. It also is widely distributed in ordinary foods, and it would be difficult to avoid getting enough in one's diet.

Vitamin authorities have deplored the general tendency to worry about each of the latest vitamins, when but a relative few are really important. For instance, in an address given when he received the Chandler Medal from Columbia University, Dr. Robert R. Williams said:

I should like to divert the minds of food processors, teachers of nutrition, practicing physicians and laymen from speculating about the latest surmise of vitamin science and persuade them to devote their major energies to the intelligent application of the vitamins which stand in the front row of the shelf.

These are six in number: Vitamin A, thiamin, riboflavin, nicotinic acid, ascorbic acid (Vitamin C) and Vitamin D. The others, as Dr. Williams was careful to point out, cannot be said to play less essential roles in human physiology, for their lack would undoubtedly cause grave disorders. However, the chance of anyone whose diet is adequate failing to get ample quantities of them is so slight that this does not constitute a present health problem.

Of the "vital vitamin" sextette, we first have Vitamin A. Chemically, it belongs to the class of alcohols, and it is necessary for several bodily functions. It is essential for the formation, in the retina of the eye, of "visual purple." Without this substance, vision, particularly at night and under low intensity of illumination, is greatly impaired. That is why Vitamin A has been given to night-flying aviators in order to help them see clearly enemy planes and other objectives. When it is lacking, the epithelial tissues of the body, such as those in the respiratory and digestive tracts, are injured, and the eyes are inflamed. There may also be retarded growth and lowered resistance to infection.

Thin-leaved green plants used for food, such as green lettuce, spinach, turnip greens, escarole and chard are, in general, good sources of this vitamin. Also included among foods from which our best supply comes are carrots, apricots and yellow sweet potatoes. The materials that are responsible for the yellow coloring of these and other fruits and vegetables (compounds known as carotenes and cryptoxanthin) are converted to Vitamin A in the body. Stable to heat, acids and alkalis, they survive cooking but are broken down by the action of light. Vitamin A is stored in the liver, so temporary shortages are not serious. Pregnant women and nursing mothers require more than the usual amount.

Next in our list of the important vitamins comes B₁, or thiamin. This helps to oxidize carbohydrates, such as sugars and starches. Without thiamin the tissue cells are starved. This produces injury especially to nervous tissues, so that in advanced cases polyneuritis or beriberi results. In milder cases there may be only loss of appetite, retarded growth, faulty digestion and nervousness. The more active a person, the more thiamin he needs, and, in general, men require more than women. Since it is essential for pregnancy and milk production, expectant and also nursing mothers need a particularly ample supply. It is not stored in the body to any extent, so it should be taken daily.

Among the excellent sources are bran, whole or embryo grains, yeast, nuts, dried legumes, lean beef, lean pork, soy beans and dried whey. As thiamin hydrochloride, the synthetic form may be taken when natural sources are lacking or deficient. Enriched bread and cereals, of course, give adequate amounts. Since it is destroyed by heat, particularly when accompanied by moisture, cooking is apt to reduce somewhat the potency of thiamin-containing foods.

Riboflavin, once called Vitamin G, now is sometimes known as Vitamin B₂. Perhaps it acts, along with thiamin, in the burning of carbohydrates. No familiar disease is caused by its lack, but some of the effects of such deficiency—soreness of the lips and cracks forming at their angles—have been confused with the

effects of pellagra. Without it there is also burning and redness of the eyes, possibly even blindness. In the eyes of young rats deprived of riboflavin, cataracts are easily formed; but fortunately the symptoms caused by its lack are rare in man.

It is widely distributed in many foods of animal as well as vegetable origin. Milk, green leaves of growing plants, beef and pig liver and kidney, mackerel and oysters are all good sources of riboflavin. Stable to heat, it is sensitive to light. Since it is soluble in water, prolonged boiling of foods may extract the vitamin from them. However, if the water in which they have been boiled is used for other purposes, as in soups, the body will still get its supply. Prepared synthetically, riboflavin is available commercially in pure form as a light-yellow powder.

Next on our shelf is nicotinic acid, which was first synthesized in 1873, long before vitamins had been heard of. In spite of its name, it is not obtained from tobacco, and it is entirely different from nicotine, which is a deadly poison. Nevertheless, to allay fears of those who might believe that they were being poisoned by nicotinic acid in their bread, the name has been changed on the recommendation of the food and nutrition board of the National Research Council. It is now called niacin, or niacin amide—the latter in place of nicotinamide, a form in which it is frequently used. It has also, in the past, been referred to as Vitamin P-P, the letters standing for “pellagra preventive” since its lack is responsible for this disease.

It was in 1937 that Dr. Elvehjem ascertained that niacin was present in yeast and that it cured blacktongue in dogs. Dr. Tom D. Spies of the University of Cincinnati was one of the first to apply it to the cure of pellagra in man. Exactly what it does in the body is still uncertain, but a pellagra victim begins to show improvement very soon after taking it. The disease is prevalent in the South, and nutrition experts are of the opinion that it is best in that region to give niacin through its addition to common foods. This is easier than persuading the people subject to pellagra to change their long-established food habits. Ex-

cellent sources of niacin are bran, eggs, fish; heart, liver and kidneys of animals; lean meat, peanuts, wheat germ, dried whey and yeast. Though not affected by heat, like riboflavin it is soluble in water, and may be extracted from foods by prolonged boiling.

Vitamin C, in its pure form as a white crystalline powder, was first isolated from lemons by Dr. Charles G. King of the University of Pittsburgh in 1932. The following year he made it synthetically. About the same time it was independently prepared by Dr. Albert von Szent-Györgyi from the paprika of his native Hungary, and it was he who named it ascorbic acid. This work won for him the 1937 Nobel Prize in Medicine.

In the body, ascorbic acid seems to be needed in the manufacture of "cement substance," responsible for holding together the cells of bone, teeth and connective tissue, as well as tissues generally. Loss of appetite, fatigue, anemia and weakness may appear when it is deficient. If the condition continues, scurvy develops. As with other vitamins, nursing and expectant mothers need more (about twice as much) as other adults.

Lemons, oranges, grapefruit and limes are excellent sources of ascorbic acid, but oxygen in the air quickly destroys it. Thus, the potency of the juices of citrus fruits is soon lowered if they are allowed to stand. For this reason orange juice should be squeezed from the fruit immediately before it is used. Beet greens, broccoli, cabbage, cauliflower, green and red peppers, tomatoes, strawberries, spinach, green peas and liver are also excellent sources. However, the ease with which the vitamin is destroyed not only by the air but also in cooking means that the sources should be used fresh and raw wherever possible. If an adequate supply from food is not available, pure ascorbic acid may be taken.

Vitamin C also promises to be an important aid in the prevention of heat prostration among industrial workers and others who are exposed to the effects of high temperature and humidity. A few years ago a South African physiologist found that native Bantus, working in the gold mines of the Witwatersrand,

frequently contracted scurvy, although their diet contained adequate amounts of ascorbic acid. Tests proved that most of it was lost, before it did any good, in the perspiration which was most profuse under the hot humid conditions existing in the mines.

In the summer of 1939, at one of the Du Pont cellophane and rayon plants in the South, a group of men had to make an emergency repair above a hot drying cabinet. For several weeks, while they were doing this job, they were exposed to temperatures well above 100° Fahrenheit. Previously, when at such a task, each man would take a salt pill every time he took a drink of water. This has long been a standard practice, as much of the body's salt is lost through perspiration, and there may be ill effects if it is not replaced. In spite of this, however, a number of the workers had suffered heat cramps and heat prostration.

On this occasion Dr. W. L. Weaver, head of the plant's medical unit, had the men take Vitamin C in addition to the salt. At morning and at night they received 50 milligrams. The total amount, 100 milligrams, is well above the normal daily requirement. During the course of the job not a man suffered from heat cramps or collapse. Except for one man (who had been drinking over the week end) they did not even show any variation in blood pressure, which is a sign of incipient heat prostration.

As a result of this experience all the employees of the plant have been given daily doses of vitamins, including not only C but B₁ as well, since this also is known to be lost in the perspiration. Almost no cases of heat cramps or exhaustion have occurred since, though formerly the dispensary had four or five cases a day in hot weather.

The part played by Vitamin B₁ in connection with heat effects is not very well understood, but Vitamin C is believed to be associated with the action of the muscles. Even when our bodies are still, our muscles are continually contracting. This is called muscle tone, and is important, along with the usual

muscular activity in movement, in pushing blood through the veins back to the heart. Vitamin C, it seems, helps maintain muscle tone. Said Dr. John H. Foulger, director of the Du Pont Company's Haskell Laboratory of Industrial Toxicology, in a report on this work which he gave the Millbank Memorial Fund:

In heat prostration the muscle tone is diminished. Likewise the blood vessels of the skin are dilated in an effort to pipe greater amounts of the heat-laden blood to the surface where it can be cooled. This leaves less blood in the large internal vessels, gives the heart less to pump against and further adds to the collapsed state of the circulation. These two factors, the necessity for the muscles to push the blood up to the heart against the force of gravity, and the dilation of the peripheral vessels in hot weather, are principal reasons why people often faint while standing to watch a parade in the summer time, or why soldiers sometimes faint when standing for long periods at attention. In both cases the muscles are fairly inactive. Vitamin C prevents this, we believe, by maintaining the muscle tone both in the large muscles and in the small ones of the walls of the arteries and their branches.

Thus it would seem that lemonade, if it is strong enough, has a beneficial effect in hot weather aside from its relief of thirst.²

In Vitamin D we have a very different state of affairs from that of the others mentioned. Vitamin D is not a single chemical substance; but probably more than a dozen different compounds, belonging to the class of "sterols," can be made to show its properties. Chief of these is that, in the body, it aids absorption of calcium and phosphorus from the intestines. It maintains the proper amount and form of these elements in the blood—thus the growth of bones and teeth is assisted. Rickets, which is a failure of the body to deposit calcium and phosphorus in the bones of children, and osteomalacia, a comparable disease

² This treatment is directed against heat exhaustion, not heat stroke or sun stroke. In heat exhaustion or heat prostration, which is more common than the stroke, the patient is usually conscious. He is covered with cold sweat, breathing is shallow and rapid and the pulse is rapid and feeble. Heat stroke, on the other hand, is indicated by dry, hot skin and flushed face, while the victim is always unconscious.

of adults in which the bones soften and break easily, result from the lack of an ample Vitamin D supply.

Studies of this vitamin have given some justification to the sun worshipers. Unlike the others, which are taken into the body in some solid or liquid form, Vitamin D can be obtained by exposure to the ultraviolet rays of sunlight or in the radiation of a sunlamp. There is in the body a material called cholesterol, and these invisible rays confer upon it the beneficial qualities of the vitamin. Some animals are covered with much hair that prevents the sun's rays from reaching their skin. In their hair is a compound similar to cholesterol; this also is activated by the ultraviolet light; then, as the animal licks itself, the vitamin is taken into the body.

Dr. Harry Steenbock, of the University of Wisconsin, invented a process by which artificially produced ultraviolet rays may be used to irradiate many foods, such as milk, and give them the beneficial properties of Vitamin D. Ergosterol, another member of the sterol family, is similarly irradiated—then it is called "viosterol" and used as a source of the vitamin which can be taken in a convenient form. Bombardment by the tiny particles called electrons also is able to activate these substances.

Among the relatively few foods which normally contain Vitamin D are salmon, tuna, herring, sardines, egg yolk, cheese, butter and chocolate. Even more fully provided with the anti-rachitic properties is halibut liver oil, probably the best natural source, and cod liver oil, to a lesser degree. Sunlight, however, is the best way of providing its protection. And, once more, nursing mothers and pregnant women have particular need of its qualities.

Departing now from these fields of vitamin study where knowledge is fairly well established, we find on the frontiers many new and apparently unrelated data which future work-

ers will have to correlate. Some of these, interesting to everyone because they concern one of the more obvious effects of aging, bear upon the influence of vitamins on the graying of hair.

A few years ago it was found that pantothenic acid, given in daily doses from infancy, seemed to prevent the hair of black rats from turning gray. If the diet of the rats was deficient, and their hair did turn gray, the black was restored when this vitamin was given. The reaction of rats to food is in many respects similar to that of man, and they have helped to reveal a large part of our knowledge of the action of vitamins and other food elements. Consequently there seemed to be some hope that these findings might be applied to human beings. However, Dr. Robert Williams repeated the rat experiments, only to find that, under his conditions, "neither pantothenic acid concentrates nor pure pantothenic acid exhibited a preventive or curative effect on the gray hair of rats, although the rate of growth and the length of life were greatly enhanced."

Then, at a meeting of the American Chemical Society in 1941, Dr. Gustav J. Martin, of the Warner Institute for Therapeutic Research, and S. Ansbacher, of the International Vitamin Corporation, reported that another B vitamin, para-aminobenzoic acid, seemed to accomplish the desired results in man. Giving small daily doses to thirty patients, they found a marked darkening of hair already turned gray along with a growth of new, naturally colored hair. Similar results were obtained by others, but, on the other hand, para-aminobenzoic acid did not seem to produce any effect on rats.

Then also inositol, another member of the B complex, seems to have a role. In experiments by Dr. D. W. Wooley at the Rockefeller Institute it was found to prevent baldness, provided it was given in conjunction with the para-aminobenzoic acid. When the experimental animals were given the acid but no inositol, they became bald. And early in 1942, to the American Institute of Nutrition, Dr. Martin reported that lack of the acid

resulted in gray hair in animals only when pantothenic acid and inositol were fed in effective quantities. That is, a lack of all three did not produce the gray hair.

At this same meeting, Dr. Ansbacher told of experiments in collaboration with Dr. Martin and Dr. W. A. Wisansky, of the American Home Products Corporation. Their subjects were thirty gray-haired persons who were under just as close control as laboratory animals—they were inmates of a prison. Each day for eight months they were given 100-milligram para-aminobenzoic acid tablets. At the end of the period more than two-thirds of the men had the original color of their hair at least partially restored.

Because of the conflicting results in this fascinating field, there is no doubt that the complete answer is yet to be found. Perhaps, however, it is no worse than was the position in regard to beriberi in 1910. Modern workers have as a guide the past studies which the vitamin pioneers lacked, so it is not too much to hope that a correct answer may be found. Not only gray hair and baldness, but also other concomitants of old age may similarly be alleviated with vitamins. Then, with the aid of other medical advances, science may have made an approach to achieving that fountain of youth which Ponce de Leon vainly sought.

X. *New Metals*

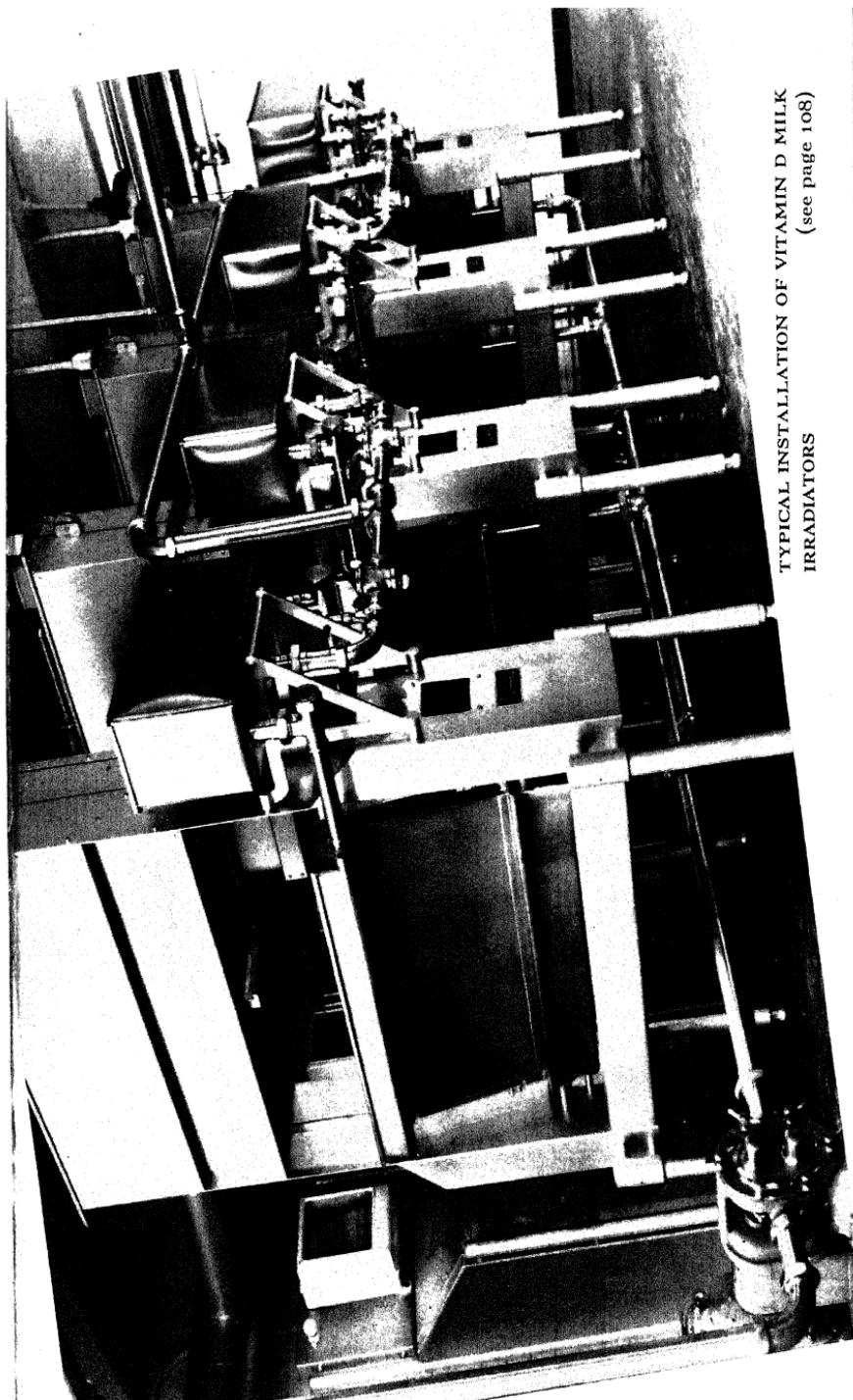
With the use of metals going back to the dawn of human history, it may, perhaps, seem surprising to speak of "new" ones. About 60 of the 92 known chemical elements are metals. These have always existed, though man may not have discovered them until recent times. Many of them did not exist in their metallic form until it was found how to extract them from the compounds, the "ores" in which they occur in nature. And even aside from these, there are "new" metals. They are the alloys, mixtures of two or more other metals, which metallurgists have fashioned with startling results; for they have a range of properties far greater than those of the metals of which they are made. Some are hard, some are soft. Some can be magnetized most strongly, others are as little affected by magnetism as wood. Some are twice as dense as iron, while others are nearly light enough to float on water. Without their development, our civilization would be very different. There would be none of the high-speed trains or powerful automobiles to which we are used, no modern airplanes, no inexpensive and efficient electric lamps or radio tubes.

Copper occurs free in nature; it was the first metal to be used by early man, since it is soft enough to be hammered easily into the shape of the tools that he desired. Then it was refined from ores, particularly copper oxides, from which the metal could be extracted easily. This all started before the beginning of historical records; and next, it is conjectured, some ingenious primitive metallurgist found that a small amount of tin mixed with copper made its strength much greater than either of the original two metals. This mixture is bronze, the first alloy to be made by man, though it may not have been the first he used.

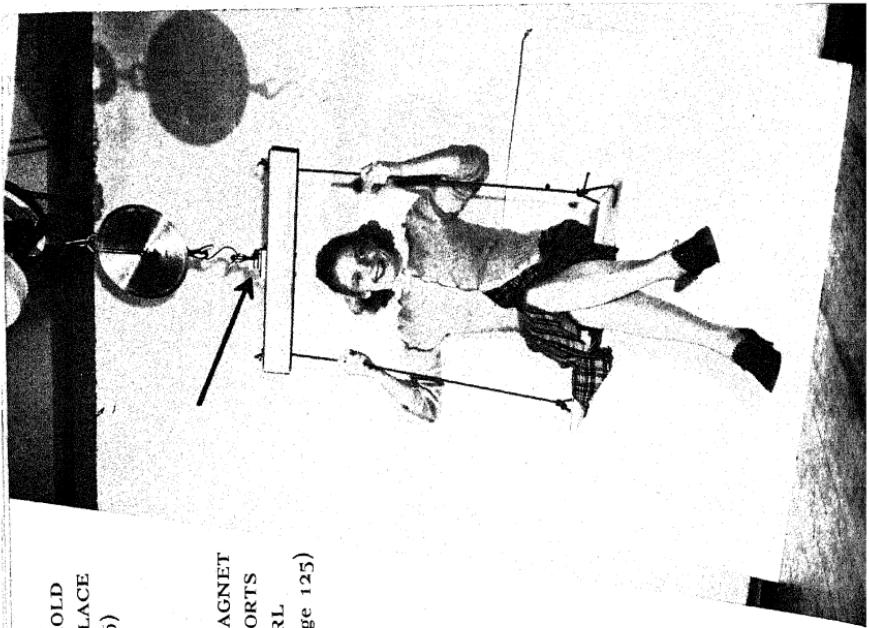
Long before life appeared on the earth, nature had been bombarding our planet with pieces of an alloy of iron and nickel—in the form of meteorites. Many millions of meteors enter the earth's atmosphere daily, though seldom is one sufficiently big to survive the heating it receives in that passage. But when it does, and lands on the earth, then it is a meteorite. Without much question, primitive men found such pieces of metal and made use of them. The supply of this natural iron alloy was severely limited, and bronze was the first alloy to be widely employed. In the development of many cultures, archaeologists recognize the Bronze Age as an important period, following an age when stone weapons and tools were used. Peoples of Europe, Egypt, much of Asia, and even parts of Central America passed through a Bronze Age, and many beautiful relics of their work survive in museums. Brass, which is an alloy of copper with zinc instead of tin, came later. Probably where brass is mentioned in the Bible, really bronze was meant, for the two terms have often been used rather loosely.

Following the Bronze Age, in most cultural developments, came the Iron Age. Perhaps this began with the working of meteoric iron, or else accidentally when the metal was found in the ashes of a large fire that, so it happened, had been built against a bank of an iron-containing ore. Its usefulness discovered, the obvious step would be to build such fires deliberately, then to enclose them, making primitive blast furnaces. Like the use of glass, then, the art of working with metals and alloys is an old one. But, again like glass, modern technical developments have vastly increased their use. Some of these improvements have been in refining methods—for example, the process by which aluminum could be made so cheaply that, in times of peace, it could be used in the ordinary household for pots and pans.

Of all metals, aluminum is most abundant in the earth's crust, but it never occurs in metallic form. Always it is in a compound, frequently of silicon and oxygen; that is, a silicate. Another common ore is bauxite, an impure oxide. There is

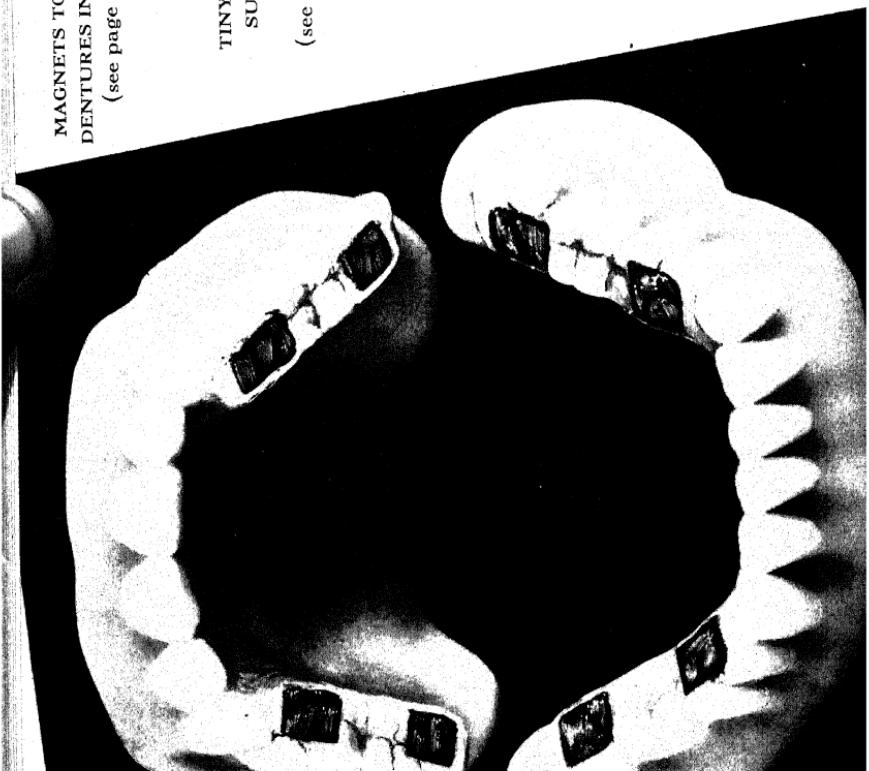


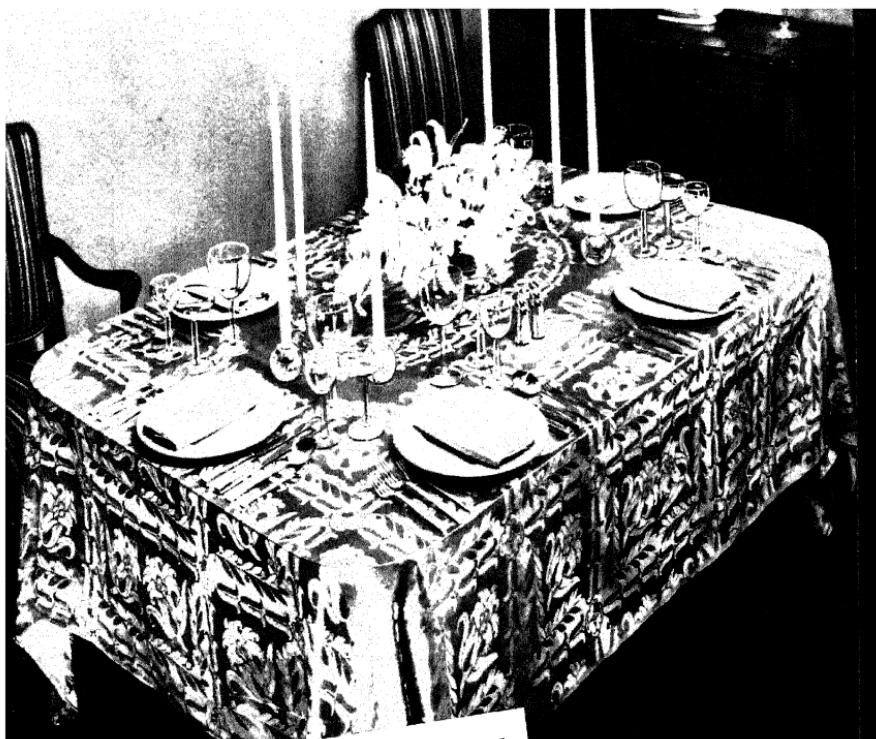
TYPICAL INSTALLATION OF VITAMIN D MILK
IRRADIATORS
(see page 108)



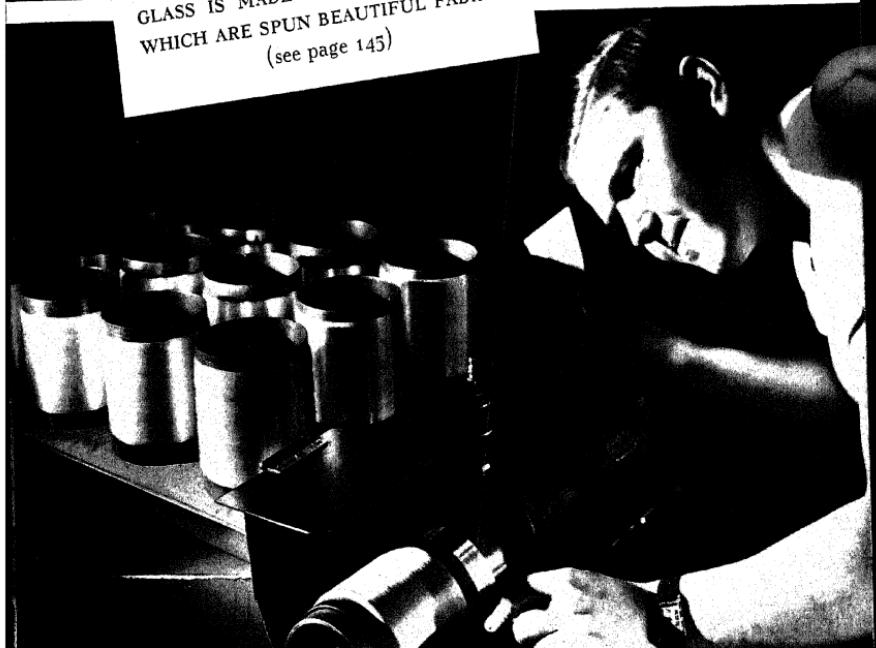
MAGNETS TO HOLD
DENTURES IN PLACE
(see page 126)

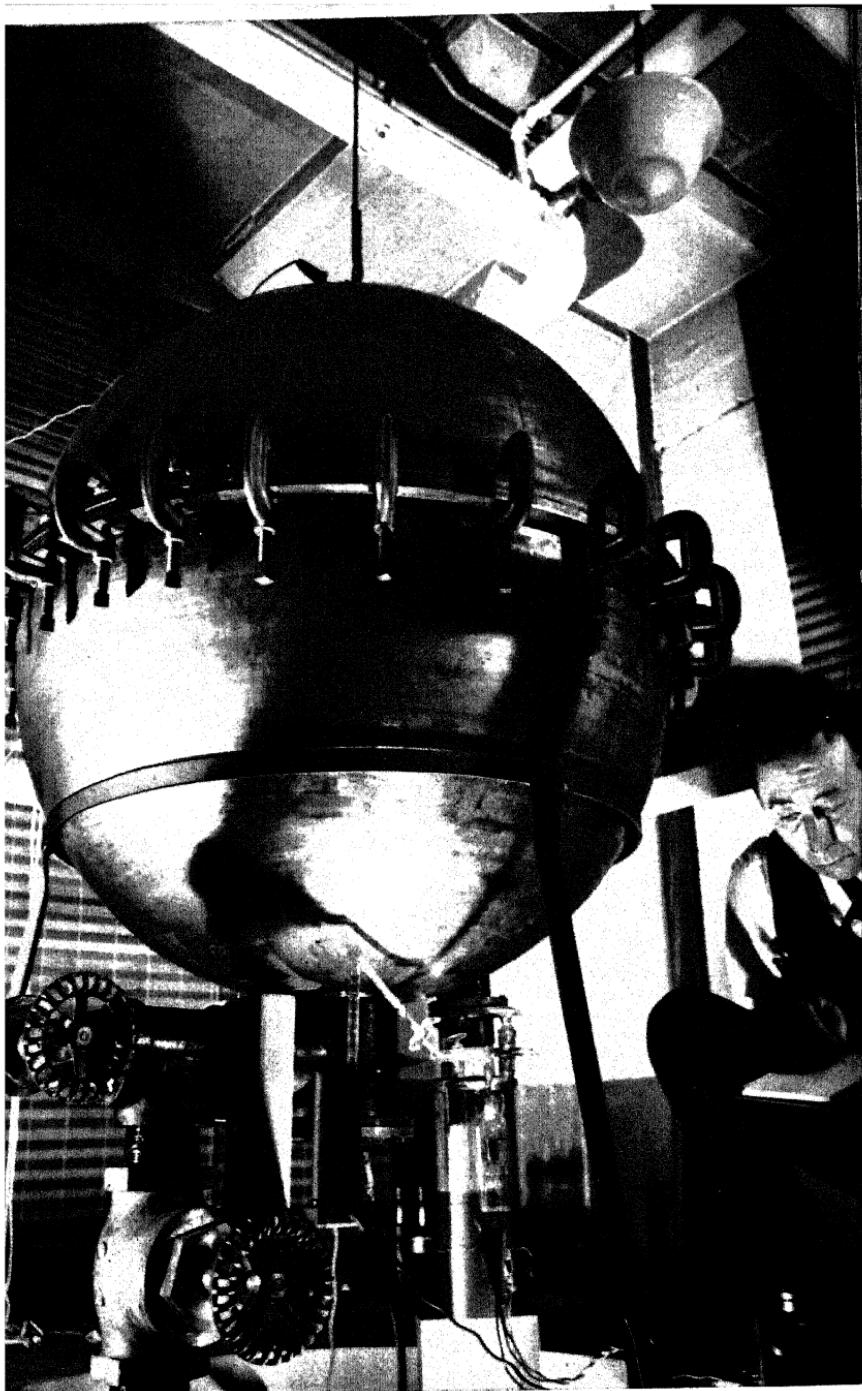
TINY MAGNET
SUPPORTS
GIRL
(see page 125)





GLASS IS MADE INTO A FIBER FROM
WHICH ARE SPUN BEAUTIFUL FABRICS
(see page 145)





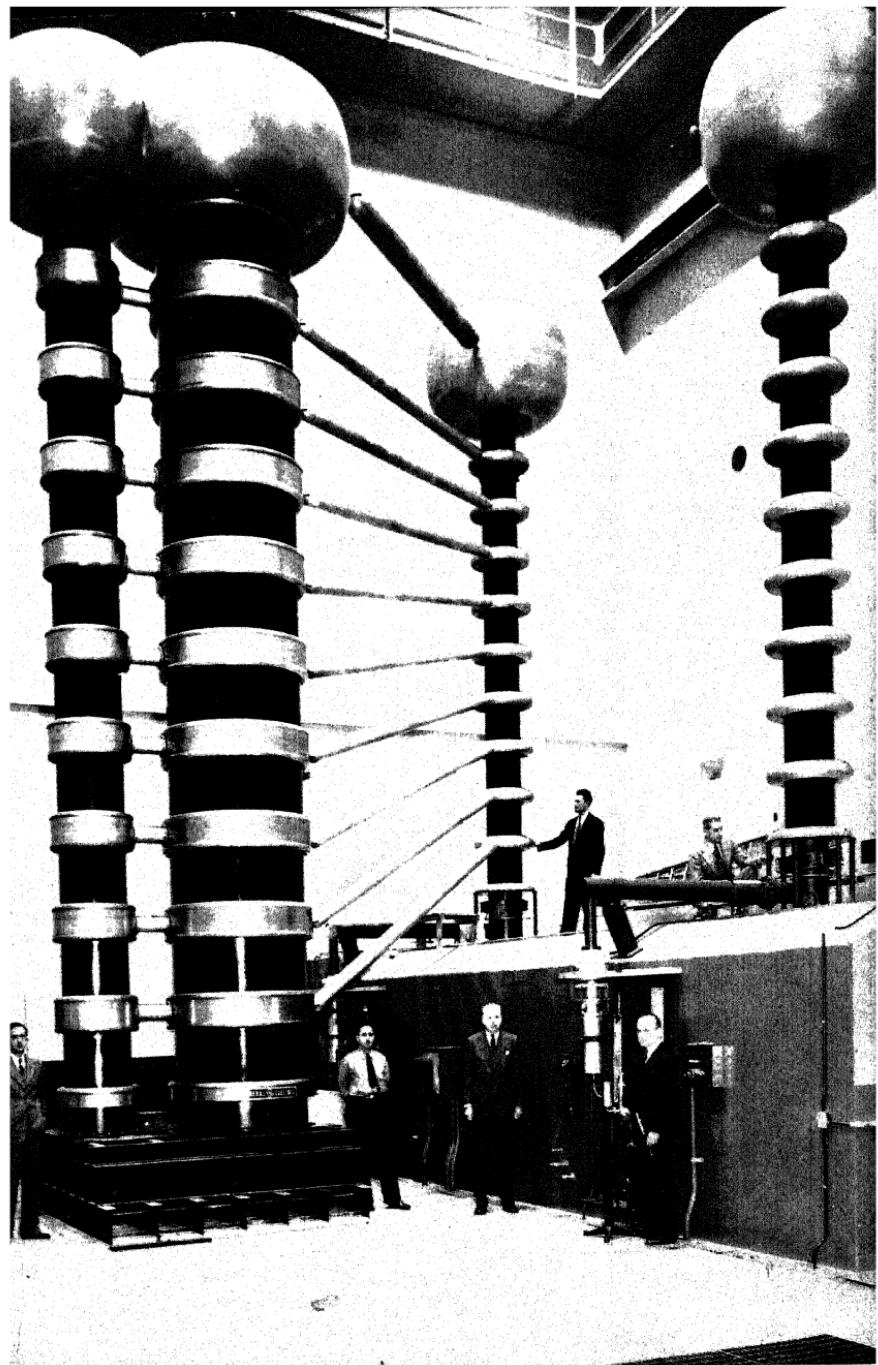
GLASS IS MADE NON-REFLECTING IN THIS GREAT SPHERE



LIKE A HUMMING BIRD, IGOR SIKORSKY HOVERS IN HIS HELICOPTER



TO MAKE PLANES FLY HIGHER—TURBOSUPERCHARGER PARTS

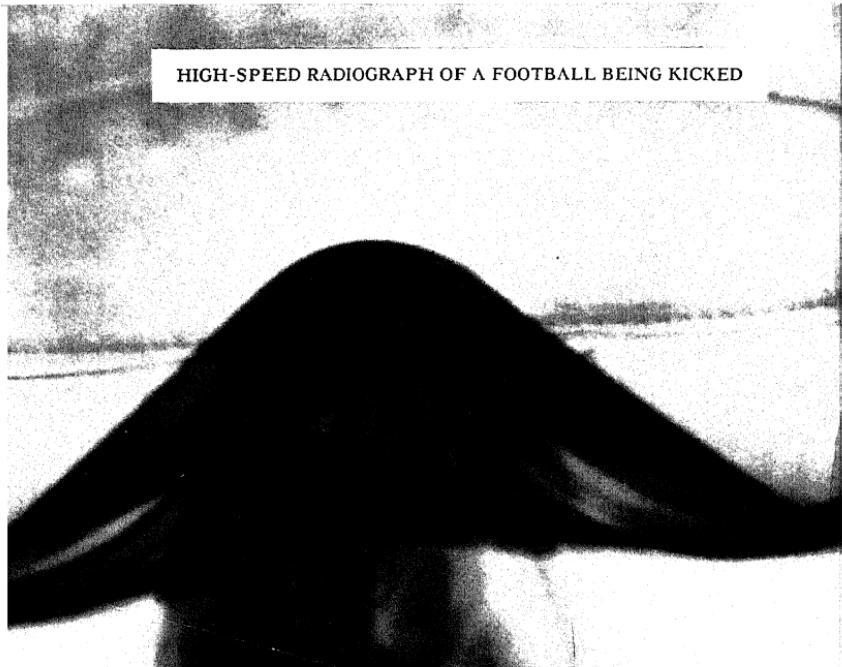


1,400,000-VOLT X-RAY MACHINE
(see page 181)

WITH MILLION-VOLT X-RAYS MEN LOOK THROUGH STEEL CASTINGS
(see pages 181-182)



HIGH-SPEED RADIOPHOTOGRAPH OF A FOOTBALL BEING KICKED



some uncertainty over who first actually isolated the metal. The Danish chemist, Hans Christian Oersted, in 1825 announced to the Royal Danish Academy of Sciences that he had obtained it, though this has been questioned, and the credit is customarily given to Friederich Wöhler, who, though unable to obtain it by repeating Oersted's experiments, did secure it by another process in 1827.

By 1855 a French chemist, Henri Sainte-Claire Deville, was able to exhibit a bar of the metal at the Paris Exposition. The Emperor Napoleon III heard of this, and realized how valuable aluminum would be for making light-weight equipment for his soldiers, to increase the army's mobility. Accordingly, with imperial backing, Sainte-Claire Deville set to work producing it commercially. Whereas it had been worth \$545 per pound in 1852, by 1856 Deville managed to bring it down to \$35, and to \$17 in 1859—when the world production was just two tons. Though this was not cheap enough to permit the widespread use that Louis Napoleon had envisioned, at least it made the metal available to scientists; and they began to recognize its potential usefulness.

In 1886 two young men, each 22 years old, independently discovered a cheap way of preparing the metal. In the United States it was Charles M. Hall, who had been graduated from Oberlin College nine months earlier, and in France it was Paul L. T. Héroult. The effect of their discoveries is shown by a comparison of the 17.6 tons which was the world production in 1886 with the 715,000 tons the world produced in 1939, a figure surpassed only by iron, copper, lead and zinc. The cost in the latter year was about 20 cents a pound.

Young Hall's discovery was no accident, but the result of a definite search. One of his professors had told him that the man who could perfect an inexpensive method of extracting aluminum from the vast stores of its compounds which lay in the surface of the earth would be a benefactor to mankind—and would make a fortune in the bargain. So, with youthful confidence, Hall set out to do it.

The process he discovered after nine months, working in his father's woodshed, started with the melting of cryolite, which is a mineral containing aluminum that is obtained from Greenland. It melts to a clear liquid at about 1000° Centigrade; and then aluminum oxide, otherwise called alumina, will dissolve in it. Hall passed an electric current through such a molten bath; the alumina was separated into its parts. Oxygen was given off and buttons of aluminum metal settled at the bottom. Thus, Hall's confidence that he could solve this old problem was justified.

Bauxite is the chief aluminum ore, and though it is aluminum oxide, it has to be purified to prepare it for the Hall-Héroult furnace. The furnace in its present form consists of an iron box, lined with blocks of carbon which serve as one electrode (the cathode), while the other electrode is a series of plates of carbon which are lowered into the box. When these are touched to the carbon lining and current is connected, an electric arc is formed, and this melts the cryolite as it is added. (Incidentally, we are not necessarily dependent on imports for the cryolite, which can be prepared artificially.) It is melted by the current and then the alumina is introduced. In modern furnaces molten aluminum flows out through a hole in the bottom, to be cast into ingots, ready for whatever use is desired.

To make a pound of aluminum requires four pounds of bauxite which, when purified, makes two pounds of alumina. In refining one pound 12 kilowatt hours of electricity, enough to supply an ordinary home for several days, is consumed, along with three-quarters of a pound of carbon in the electrode. Some of the supply of bauxite comes from Arkansas, but much of it is imported from Surinam (Netherlands Guiana). Getting the enormous quantities of electric power needed for the production of billions of pounds of aluminum is also a problem, but one which the recent hydroelectric developments on the Columbia River will help to solve.

To meet the shortage of bauxite, other processes have been developed. One, for instance, uses as the ore alunite, a reddish

mineral found in Utah and other Western states. Another process, developed at Columbia University by Dr. Arthur W. Hixson, starts with clay and other ores having a high silica content, which are found in great abundance in many parts of the country. Advances in synthetic plastics and ceramic ware, and improved methods of handling rubber, among other items, have made it possible to use hydrochloric acid in this process, which eliminates some previous difficulties. It produces aluminum chloride, which is then converted to alumina and refined by the usual method.

Shortly before World War I, Alfred Wilm, in Germany, discovered that an alloy made of aluminum with four per cent copper, one-half per cent magnesium, and one-half per cent manganese could be heated, cooled by quenching in water and aged several days to make a metal strong as steel, yet retaining practically all the lightness of aluminum. This was called duralumin, and it was employed in the Zeppelins. Modifications of this alloy are used today in most of the world's fighting planes.

Aluminum alloys, like many others, are subject to corrosion, with consequent weakening and possible failure of structures made from them. But in most cases very pure metals are resistant to corrosives, and this is true of aluminum. So the National Bureau of Standards made a suggestion, which was applied by the Aluminum Company of America's metallurgists, of coating the strong-alloy sheets with the pure metal; and this has proven of great value, especially in all-metal planes, where aluminum makes up more than three-fourths of the weight.

The advantage of aluminum's lightness for airplanes is one that can readily be appreciated, since the less the craft weighs, the more can be lifted off the ground as useful load in the form of fuel for long-range flights, passengers or bombs. But this same lightness is advantageous elsewhere. Most states have

laws limiting the gross weight of trucks on their highways, so, if the truck itself weighs less, the load can be greater yet stay within the requirements. Accordingly, aluminum has been used for truck bodies. Even in static structures, light weight is of value. In a long bridge, as much as 80 per cent of the total weight may be required just to sustain itself. If the structure is lightened by using aluminum for the flooring, that much additional live load may be carried.

Even lighter, by approximately a third, than aluminum is magnesium, which burns with an intensely white light and formerly was used by photographers in flashlight powder. Larger pieces, however, are difficult to start burning; thus the metal can be handled and worked. Even so, high enough temperatures will start ignition—the principle by which magnesium is used in incendiary bombs. In the bomb is a thermit mixture, of iron oxide and aluminum, which burns with great heat; its main use is normally for welding. In the bomb, it easily generates sufficient heat to start the magnesium.

In construction work, magnesium is never used alone, but always as an alloy. These alloys, usually with aluminum, are known as Dowmetals, after the Dow Chemical Company, principal producers in the United States of magnesium, which introduced them. A typical alloy of this type, known as Dowmetal A, contains 92 per cent magnesium and eight per cent aluminum, which is many times harder and stronger than magnesium alone. This alloy has the advantage of being highly resistant to corrosion.

The Dow Chemical Company entered the magnesium-metal field as a result of World War I; and thanks to their pioneering, we had the nucleus of a large productive capacity when we entered World War II. In 1914 Dow was producing and marketing magnesium chloride and calcium chloride, used in cements at that time. The magnesium salt had been imported from Germany, but when this was no longer available Dow started producing it. The source is the great subterranean salt lake which underlies part of Michigan between Lake Huron

and Lake Michigan. The brine from this lake is pumped to the surface, and more than 300 useful products are made from it. It was experience with this brine that gave the Dow chemists the background to enable them to mine the ocean itself for magnesium, and also for bromine, used in making ethyl gasoline.¹

But still the most important of our metals is that same one which was used thousands of years ago in Egypt, and which makes up almost a twentieth of the earth's crust. This is iron, and fortunately the United States is amply provided with its ore, largely of iron oxides, similar in its red color as well as its chemical makeup to the rust which forms on iron when exposed to the air. Iron is strong when mixed with carbon; steel is the result. It can be hardened by quenching—that is, heating it and suddenly cooling it by plunging the piece into a liquid such as water or oil. Since steel, as well as iron, is subject to corrosion in its ordinary form, in recent years increasingly large quantities of "stainless steel," developed by metallurgical research in the United States, in England and in Germany, have come into use.

Chromium is the secret of stainless steel, and to deserve the title an alloy must contain at least 12 per cent of this metal. Some contain as much as 25–30 per cent, though these are used more for resistance to heat than to corrosion.

Cutlery was the first application of stainless steel to have wide use, as the result of the work of an English metallurgist, Harry Brearley. Studying steel alloys that might be used to line rifle barrels, he happened in 1912 to make one containing 12.8 per cent of chromium with the iron. When samples were sent to the laboratory for examination, it was found that they were very difficult to etch with nitric acid. Brearley realized the value of

¹ However, there are also other sources of magnesium, and a plant has been erected with government aid in California to make magnesium from magnesite, a mineral found in Nevada.

such a steel for cutlery, since it would not be affected by acids in foods; but at first he had difficulty in interesting the manufacturers. In 1914, however, they began to use it for knives.

About the same time F. M. Becket, in the United States, was interested in finding an alloy that would withstand temperatures up to about 2000° Fahrenheit without oxidizing. He found that 20 per cent or more of chromium with the iron gave excellent resistance.

Also seeking a heat-resistant metal were two German scientists, Benno Strauss and Eduard Maurer, of the Krupp Works. As early as 1910 they had prepared alloys with 20 per cent of chromium; and they found that these remained bright while others, even with a quarter nickel, became rusty when exposed for some time to the air of the laboratory. Then they experimented with the resistance of metals to corrosion by fresh and sea water, and tested alloys not alone of chromium but also of nickel and chromium with iron. From this work came "18-8," which consists of 18 per cent chromium, eight per cent nickel and the balance iron, today the most popular of the stainless steels.²

Denser than aluminum, stainless steel weighs more than that metal, volume for volume. But because it exceeds aluminum in strength, in many cases less stainless steel need be used. Consequently, for comparable weights, the two metals compare favorably in strength.

² In 1940, 276,698 tons of stainless steels were produced in the United States, as compared with 59,270 tons in 1930. Nearly 45 per cent of the 1940 figure was "18-8." The greater part went to the automobile industry, which used it for trim and corrosion-resistant outside work on cars. Patents were applied for in October, 1912, by the Krupp Company, and they were granted in the United States as well as in Germany and other countries. After we entered World War I, the American patents were confiscated by the Alien Property Custodian and made available freely for the use of the Allies. After the War they were turned over to the Chemical Foundation, which profited by the license fees for their use. Thus the Foundation was able to do a valuable task in aiding research, and also in popularizing the findings of the chemists. It was on the basis of these patents that extensive American production was begun by the Allegheny Ludlum Steel Corporation, and later by the U. S. Steel Corporation, the Crucible Steel Corporation, and others.

Other metals are alloyed with iron in the various kinds of steel—manganese, for example, gives great strength and resistance to cutting, so it is used for jail bars. But all steel manufacture makes use of small amounts of manganese. About 14 pounds of the metal, in combination with iron, go into every ton of steel that is made. One reason is that it takes care of the sulfur that is present in practically all iron, and which can be removed only at considerable expense. Without manganese, the sulfur unites with the iron chemically, forms an iron sulfide at the boundaries of the metal grains, and causes weakening of the structure. Since Russia, Turkey and the African Gold Coast have been the main sources of this metal, for which no substitute has been found, our government is vitally interested in manganese.

In tungsten we have a metal that is not only the source of much of the world's illumination in the Mazda lamp; when alloyed with iron it also does most of the cutting of other metals in the lathes, milling machines, planers and shapers of America's machine shops. This development was brought about by Elwood Haynes, automotive pioneer who had made experiments with combinations of nickel, cobalt and chromium as early as 1895. From 1907 to 1913 Haynes was searching for durable spark-plug electrodes. Cobalt, chromium and tungsten alloys, in which iron was present, if at all, only as an impurity, proved the best, and were known as Stellite. It is used today for cutting tools, along with other alloys of tungsten with iron.

Steel containing tungsten is hard and tough, and, even more important, it retains these qualities when hot. Thus it is possible to run machines so fast that the tungsten-steel tools used for cutting edges actually heat to redness without dulling. And the faster the machines can be run, the more production may be speeded. Even better than tungsten steel is a compound of tungsten and carbon, sometimes with titanium as well, which is called Carboloy. Invented at the Krupp Works in Germany, it was developed in the United States by the General Electric

Company. Tools of Carboloy can be run still hotter, up to as much as 1500° Fahrenheit, thus further accelerating production rates.

China and Burma have been the chief sources of tungsten in the past, but some deposits of its ores have been found in the Western states, particularly California, Nevada and Arizona. In searching for the ore, prospectors often work by night and take advantage of the same "black" light that makes possible modern fluorescent lamps. Scheelite, one tungsten ore, is calcium tungstate, a fluorescent mineral. That is, when invisible ultraviolet rays fall on a piece, it gives them back in the form of visible light. For the use of the prospectors, a portable battery-operated ultraviolet lamp has been developed. The prospector carries this into the field, and shines his lamp on the places where he suspects tungsten may be found. If scheelite is present, it glows with a greenish color.

Fortunately there is a substitute for tungsten in some cutting tools—molybdenum, a heavy metal of which the United States possesses nine-tenths of the world's supply. And two-thirds of this comes from a single location in the mountains of Colorado. In addition to its use in tools, "moly," as it is familiarly called, is alloyed with steel for other purposes. Molybdenum steel has little "creep," which is a slow flowing of the metal under strain when it is hot.

That oldest of metals used by man—copper—still retains its important place. Its alloys in the form of the various bronzes and brasses, and with nickel in the form of Monel metal widely used in chemical industry, take a large proportion of the production of copper. Luckily this metal is plentifully found in the United States, as at the Leonard mine of the Anaconda Copper Company, half a mile or more below Butte, Montana; or the open-pit mine at Bingham, Utah, where the ore, though of relatively low grade, is so easily accessible that it need just be

scooped up from the surface. And in Arizona there is the similar Morenci mine of the Phelps-Dodge Corporation.

To recover all the copper from these ores some surprising methods are used, one of which is the seemingly magical way in which old pieces of iron are apparently changed to copper. According to the story, some years ago a man named Jim Lefad lived in a Montana town near a copper mine, and a stream of waste water from the mine flowed through his back yard. One day he threw into this stream some "tin" cans. (Actually these are 98 per cent or more of sheet iron, with only a coating of tin.) Next day Jim found, in place of the cans, a sludge which proved to be about 98 per cent pure copper. Contracting with the mine for all their water, he applied the process and recovered \$90,000 worth of copper the first year.

This process is now used at Butte and at other mines. Old rails, parts of automobiles, any kind of scrap iron is used, and even new iron has been employed. What happens is due to the fact that the drainage of the mines is rich in copper sulfate, or "blue vitriol"; but the group of sulfur and oxygen atoms forming the sulfate part of the compound prefers to unite with iron when it can do so. Thus, when this metal is provided, iron sulfate is formed and metallic copper remains. Copper sulfate makes the mine water blue; but it becomes yellow, from the iron salt, after the reaction has occurred.

In three plants in the Southwest, planned by the Defense Plants Corporation, old tin cans collected from towns in the neighborhood will be cleaned and shredded for use at the copper mines. A pound of copper takes the place of about the same weight of iron; so this process will add materially to the nation's copper production, but without the expenditure of other forms of scrap iron, which might have better uses. In some parts of the country, de-tinning plants are in operation to recover the small percentage of tin from the cans. But they cannot extract it all. The slight amount of tin remaining in the iron ruins it for most other applications, though not for the copper process.

Most operations on metal produce a certain amount of scrap, such as the shavings given off when steel is machined in a lathe. While in many cases scrap of this sort can be used, processes which consume all the metal without any waste are, in general, to be preferred. And that is one of the advantages of the new process of "powder metallurgy," which is making rapid advances for the fabrication of small metal parts, and may eventually be used for much larger ones as adequate machinery is developed.

This method is comparable to pill making; and some of the tools used are indeed simply modified pill machines. With powdered metal taking the place of the powdered drugs used for the pills, the machine exerts a pressure of from five to 100 tons per square inch and compacts the powder into a solid mass. By varying the dies used in the press, the "pills" may be made in any shape desired; that of a small gear, or perhaps an electrical contact or a commutator segment for an electric motor.

For a pill this suffices; but the metal mass, while strong enough to be handled, can still be broken by hand. It is necessary to sinter—that is, to bake it—for periods ranging from a few minutes to many hours. Temperatures used are well below the melting points of the metals, yet in some way the heat fastens the powder particles tightly together. The part shrinks in the sintering as much as 20 per cent. This shrinkage can, however, be accurately controlled, and parts be made large enough in the press so that when shrunk they are within a few thousandths of an inch of the correct size.

The great advantage of powder metallurgy is that it yields in a single process parts which do not require time-consuming machining to give them exact dimensions. This can only be done, however, if the shapes are not too complicated; for the metal powder refuses to flow around a corner, and all parts of

the shape must be directly in line with the jaws of the dies.³

With powder metallurgy materials as different as copper and graphite may be combined. And the products may be made either dense and solid, or highly porous, a somewhat unusual state for a metal. Bearings are made of this spongy material. They soak up oil and distribute it uniformly over the bearing surface. They can take up so much oil that they form an oil-less bearing which can be sealed into a machine, such as an electric refrigerator, and forgotten. Filters can be made in the same way. One, about as large as a thimble, is used for filtering the oil for Diesel engines; it can handle several gallons a minute.

Similar processes are also used in making permanent magnets out of the alloys called "Alnico," consisting of aluminum, nickel and cobalt, in addition to iron. Magnets have numerous applications, especially in electrical meters, such as the watt-hour meter in your cellar that measures your use of electricity. They are also important items in loud speakers for radios.

Until about 1930 the most potent permanent magnets were made of alloy carbon steel; then alloys free from carbon were devised, and the Alnicos are among the most effective. Five principal types of Alnico are now available, as the result of further development by General Electric scientists. Some of these alloys are made into magnets by casting melted metal in a mold; but in smaller sizes, such as the one used as a control for electric refrigerators, the most economical method is by

³ Like so many useful methods, the idea of powder metallurgy is an old one. It goes back to 1829 when William H. Wollaston, in England, used it to work platinum, which, melting at 3224° Fahrenheit, could not be fused in the furnaces then available. However, Wollaston made fine platinum wires with the powder method. Its first modern use came in 1910 when Dr. W. D. Coolidge, in the General Electric Research Laboratory, found that it was the only practical way to handle tungsten, which melts at 6100° Fahrenheit, in preparing the wires for the Mazda lamp. Thus treated, and made ductile, tungsten could be drawn through diamond dies into the fine filaments which these lamps required.

pressing from powder and then sintering. After that, the piece is magnetized by exposing it to an electromagnetic field.

The theory of magnetization is that the metal is made up of myriads of tiny magnetic "domains," each one of which, in turn, consists of a vast number of atoms. These domains are permanent magnets of microscopic size, but in the unmagnetized metal they have various directions and neutralize each other. In a piece of soft iron, which becomes magnetic while inside a coil carrying an electric current, they turn around and line up parallel to the magnetic field of the coil; but as soon as the current is turned off, they resume their original directions. In a permanent magnet, instead, they remain lined up even after the electromagnetic field is removed.

The latest type of Alnico is about thirty times better than the best carbon steel formerly used. This means that the magnet can be made smaller and still have the same pull, wherefore the apparatus using it can be made more compact. Another advantage is its resistance to heat and vibration, which quickly demagnetize the older materials.

Perhaps the most easily understood means of comparing magnets (though it is open to objections from a technical standpoint) is in terms of lifting power. As children we may have played with a horseshoe magnet, which for some reason was usually painted red. This was probably made of carbon steel, and if a half-pound magnet could support its own weight, we thought it pretty good. When chromium was added to the steel used for the purpose there was a slight improvement, and more came with the use of a tungsten steel. Then a great advance came about 1923, when Honda, a Japanese metallurgist, introduced steels containing cobalt and it became possible for a simple half-pound magnet to lift twice its own weight, or more. Aluminum and nickel were then added as well as cobalt, to produce Alnico, and one type (Alnico II) is strong enough to permit a half-pound magnet to lift nearly two and a half pounds.

The next great advance came with the discovery that the

alloy could be heated and then slowly cooled in the field of a powerful electromagnet. This product is called Alnico V; and while it contains considerably more cobalt than its predecessors, making the cost per pound higher, it is so much more powerful that a much smaller magnet will do the same work. Thus its cost per unit of energy is about the same. A half-pound Alnico V magnet will lift a bar of iron weighing nine pounds.

In smaller sizes, and with the magnets of special shape and weighing perhaps a fraction of an ounce, this ratio can be greatly increased and a magnet made to lift as much as 500 times its own weight. And from here on, still more increase can be secured with special assemblies. The record seems to be held with one devised by Goodwin H. Howe, a Schenectady metallurgist, which can lift and hold nearly 4500 times its own weight, enabling a magnet weighing three-fourths of an ounce to support as much as 200 pounds in tests.

A bar of any magnetic material, when magnetized in the normal way, has two "poles"; and when the bar is hung by a thread tied at the center, it tends to line up with the magnetic field of the earth. One pole seeks the north, the other the south. But a much more complicated type of magnet is possible with Alnico, for a bar can be given a second set of poles in the center. An Alnico disc can be magnetized with two, four, six or more poles around its edge; and this offers the possibility, which has been realized experimentally, of a train of magnetic gears without any teeth. If the discs are mounted, like little wheels, close to each other but not touching, one can be turned and the adjacent ones will follow, since unlike poles attract. The north-seeking poles of one disc then will pull on the south poles of the next, thus dragging the other disc around.

Unlike poles attract, but like poles repel each other. However, it was not until the development of these modern alloys that it became possible to make magnets so strong that one could support another in space above it by repulsion. Now an interesting application of this effect to the working of artificial teeth has been made by a New York dentist, Dr. Hyman

Freedman, using an alloy containing titanium designed for maximum permanence and repelling power.

Plates of artificial teeth are held in place by suction. No trouble is ordinarily experienced with uppers, because they cover the broad and hard surface of the roof of the mouth. But the lower plate is supported on the rim of the lower jaw, surrounded by the muscles under the tongue, which frequently move. Lower dentures are not as firmly anchored as the upper, and sometimes there is a tendency, when eating, for them to stick to the mass of food, and even to be pulled out of place, a rather disconcerting experience for the wearer.

In Dr. Freedman's invention, small Alnico magnets are placed in the plates, alongside the upper and lower molars, as shown in the illustration. Identical poles, either north or south, are all lined up in the same direction, so the upper and lower magnets push on each other with a force of about five ounces when the jaws are closed. Since the force of closing the jaws is about twenty pounds, the wearer of magnetic teeth has no trouble in closing his mouth; but the effect is of invisible springs, constantly pushing down on the lower denture and holding it in place.

Magnetic material of a different nature, yet of great importance in industry, is the steel required for the cores of transformers. These are used in the many places in distribution and use of electrical energy where voltage must be changed—either stepped up or down. Essentially a transformer consists of two coils of wire on an iron or steel core. Alternating current is applied to one coil, the primary, and a current will flow from the other, the secondary. If the number of wires in primary and secondary are the same, the final voltage will be the same as you put in, but if the turns of the secondary are only half as numerous, the output voltage will be half of the input. Conversely, with twice as many turns, the secondary will give out twice the number of volts applied to the primary. Since alter-

nating current can be transmitted much more efficiently at high voltages than at low, it is the practice, at the generating station, to step it up to many thousands for transmission and then, where it is used, to step it down again, often in several steps.

A transformer is most efficient if the core is a ring or an open rectangle, so that the magnetic lines of force which are responsible for its action can flow in a closed circuit. It is also better if the core is laminated rather than made in a solid piece. The laminations prevent "eddy currents" from flowing around in small loops inside the coil and wasting power.

The properties desired for metal in a transformer are just the opposite of those which make a magnet permanent. The transformer core should respond instantly to rapid changes, many times a second, of the magnetizing forces. In the early days of the G-E Research Laboratory, a great advance came when the youthful director, Dr. Willis R. Whitney, and a group of his associates investigated magnetic steel. Combined with independent work in England, this led to the adoption of a silicon-alloy steel, and the losses in the core were cut in two.

Until recently silicon steel was made in L-shaped plates, and these were interleaved with one L pointing to the right, the next upside down and pointing left, so that an open rectangle was formed. The L-shaped plates were cut from a wider strip of rolled steel.

In rolling steel, the atoms line up, giving it a "grain" roughly comparable to the grain of wood. It has been found that the magnetic flow in the core is easier with the grain than across it. However, in the older silicon steels, this difference was not great. In co-operation with the Allegheny Ludlum Steel Company, the metallurgists found a means of making silicon steel which could be rolled into strips while cold, instead of having to be heated. In this the flow along the grain is much better, and the flow across the grain much poorer, than in the older metal. With it L-shaped plates were no longer effective; for if one arm of the L is with the grain, the other must be across it. To permit the use of this new silicon alloy, however, an in-

128 SCIENCE REMAKES OUR WORLD

genious arrangement, called the Spirakore transformer, was brought out. The core is made of a continuous strip of steel, wound in a spiral like a clock spring. In this way transformers are made which cost less than the old types, yet are smaller, lighter and more efficient.

XI. *Mining the Ocean*

Around the middle of the last century, the "Electrolytic Marine Salts Company" was organized for the purpose of extracting gold from the sea. Plenty of gold, for the benefit of the promoters, resulted; but it came from the pockets of the investors rather than from the ocean. Actually, in a thousand gallons of sea water, there is about one cent's worth of gold; and it can be removed, though it costs considerably more than a cent to do so under present conditions.

However, sea water also contains many other elements, some of them metals, and at present two of them are being recovered as successful commercial ventures. We think of sea water as salty, and correctly, too, for sodium chloride, which is common salt, is the most abundant compound dissolved in it. In a ton of sea water, there are about fifty-six pounds of salt. Next in abundance comes magnesium chloride, of which there are about $6\frac{2}{3}$ pounds. Then come other materials in still smaller quantities.

After the introduction of ethyl gasoline had produced a demand for bromine in the form of ethylene dibromide, a chemical needed for making ethyl fluid, the usual sources of bromine were insufficient to supply the demand. There is bromine in sea water, though not in very large proportions—only about two ounces to a ton—but at this rate a cubic mile of the ocean would provide enough bromine for a plant producing one hundred tons a month to be kept in operation for nearly two hundred years. According to the estimates of geographers, there are more than 300,000,000 cubic miles of ocean, so the supply is practically inexhaustible.

The first experiments were performed in the laboratories of the Ethyl Gasoline Corporation in co-operation with the

General Motors Laboratories, and by them the process of recovering this small proportion of bromine was perfected. Then a "pilot plant" was erected at Ocean City, Maryland, to try it on a semi-commercial scale. This demonstrated that the water treated should be very free from silt, or suspended matter.

Further tests on a still larger scale, as mentioned earlier, were conducted aboard the S.S. *Ethyl*, the lake-type cargo vessel of 4200 tons that was fitted out as a floating chemical factory. This made it possible to try clean sea water from a number of places. The equipment handled 7000 gallons of water per minute; and the success of the operation showed that extracting bromine from sea water was entirely practicable.

Before this, however, the Dow Chemical Company had likewise considered the problem of extracting bromine from the sea, employing practically the same method that they used in their Michigan plant for recovering it from natural brines. Essentially this was to treat the brine, in which bromine was present as bromides, or combinations with various metals, with chlorine. Since the chlorine has a greater affinity for these metals, it steps in as a sort of chemical co-respondent; the bromine atoms are divorced and left to shift for themselves. The Dow process uses a powerful stream of air to blow the bromine out of the solution after it is free. Then it is combined with carbonates, from which it can easily and conveniently be used. From the natural brines, which contain some 25 per cent of solids, about 95 per cent of the bromine present has been consistently extracted.¹

After careful study, the site for the first plant was selected on the coast of North Carolina, near Wilmington. A ninety-acre tract was purchased between the Cape Fear River and the ocean. This is north of the mouth of the river. Since the

¹ The process used on the S.S. *Ethyl* had been rather more complicated and less efficient, and employed another and more expensive chemical, aniline, in its operation. Tribromoaniline, instead of ethylene dibromide, had been produced for combining with the tetaethyl lead. However, it was decided to use the Dow process, and in July, 1933, the *Ethyl*-Dow Chemical Company was incorporated, owned jointly by the two parent groups.

water of all streams entering the Atlantic Ocean flows southward, this site was a great advantage—the treated water, from which the bromine had been removed, could be exhausted into the river. Then it would flow into the ocean where it could not dilute the incoming water.

The first working drawing was completed on August 14, 1933, and less than five months later, on January 10, 1934, the production of ethylene dibromide commenced. Each day, at first, 30,000 gallons of water passed through, yielding 15,000 pounds of bromine, an efficiency of about 90 per cent. Since then the capacity of the plant has been doubled, and a second one has been established in Texas.

Sea water is slightly alkaline, so, at the start of the process, sulfuric acid is added to it. Then chlorine gas is introduced and the mixture is sprayed down the inside of a tower. Here the air-pressure force blows the bromine out and carries it up and over into another tower, where a sodium-carbonate (soda ash) solution is sprayed into it, and a solution of mixed sodium bromide and sodium bromate accumulates at the bottom. With the use of more sulfuric acid and steam, bromine is extracted as a heavy brownish-red liquid. Since this has a highly corrosive effect and is therefore difficult to ship, it is first made into ethylene dibromide by combining it with ethylene gas made from alcohol.

The success of these plants clearly demonstrated the practicability of recovering bromine from the sea, and immediately those familiar with the process began to wonder whether some others of the elements in the ocean could not be secured in a comparable manner. The next step was brought about by World War II, and America's decision to become the arsenal of the democracies.

Airplane production requires, in enormous quantities, the two light metals aluminum and magnesium. Between 1927 and 1940 the Dow Chemical Company had been the only American

producer of magnesium. In 1914, at the outbreak of World War I, they had been using magnesium chloride, imported from Germany, for making the magnesium-oxychloride cements that were then widely used. When the supply was cut off, the company began producing its own magnesium chloride from the natural brine that was already furnishing its calcium chloride. In 1915, however, there was no commercial demand for magnesium metal, except in very small amounts for photographic flash powder. It sold then for \$5.00 a pound.

However, the Dow chemists began producing the metal in 1918, and developed a whole series of alloys with magnesium as a base, known under the general name of "Dowmetal." The strength, lightness and resistance to corrosion of these alloys led to wide use, especially, as already noted, in airplane parts. To produce the enormous quantities needed for war material, every source had to be explored, including the ocean. About 3.8 per cent of the salts dissolved in sea water is magnesium. This is about 0.14 per cent of the total ocean, a figure which seems rather low. However, it means that there are about 4,555,000 tons of magnesium in a cubic mile of the sea, or enough in a single cubic mile to supply 400,000,000 pounds a year (the projected U. S. production) for twenty-two years!

Early in 1940, anticipating increased war requirements, the Dow company began the construction of a plant on the Gulf Coast of Texas to mine magnesium from the sea—a process requiring that about eight hundred tons of sea water, which is the raw material, be handled for every ton of magnesium secured. The location is at the mouth of a river where there is a deep horseshoe bend. Formerly this bend frequently obstructed the river's course and caused floods, so, in 1929, a new channel had been dug straight from a point above the bend to the Gulf, and the old river course was left as a deep-water channel. It was the tongue of land inside the old horseshoe bend that was selected.

Sea water is taken from the new channel and the exhaust

water poured into the old river. Its mouth is south of the ship channel. Currents along the Gulf Coast, as along the Atlantic shore, tend southward, so the waste waters are carried away from the intake. In addition to the magnesium plant, the Ethyl-Dow Corporation's bromine plant was erected on the same peninsula, as well as a Dow plant for obtaining useful chemicals from the plentiful supply of natural gas. So the whole group of factories form a curious combination—their raw material is water and gas!

Water pumped from the ship channel at the rate of a quarter-million gallons per minute is strained through screens, then divided, some going to the bromine plant, the rest to the magnesium installation. Of course there is plenty of water—otherwise the same water might be used in both. The sea water is mixed with a thick paste of lime (made from oyster shells) which reacts with the magnesium salts in the water to form magnesium hydroxide. This in turn is treated with hydrochloric acid to form magnesium chloride, which is then dried. After that it is melted in a furnace, and an electric current decomposes it into magnesium and chlorine. The metal, being lighter than the molten chloride, floats to the top, so it is skimmed off and cast into pigs two feet long and four inches square. Because magnesium is so light, however, these pigs weigh only seventeen pounds each. A piece of iron the same size would weigh ninety-seven pounds. The chlorine given off is not wasted, but is fed into a gas flame to make more hydrochloric acid, which is used over again.

The success of this process, and of the bromine plants, has naturally led chemists to look longingly at the other elements present in the ocean in such enormous quantities. Dr. Frank Wigglesworth Clarke, of the U. S. Geological Survey, once estimated that the volume of the ocean is 302,000,000 cubic miles. With 3.5 per cent of solid matter dissolved in the water, this would mean 4,800,000 cubic miles of salt, or enough to cover the entire United States to a depth of more than a mile

and a half. Even of elements present in extremely small proportion there are still gigantic amounts.

The possibility of securing gold from the sea has always been a most intriguing one, as witness the success (for its promoters) of the Electrolytic Marine Salts Company. Soon after World War I the great German chemist Fritz Haber, whose process is used for recovering nitrogen from the atmosphere, thought that he could get gold from the sea cheaply enough to help his country's economy. Unfortunately he used a figure for the percentage of gold which, though it came from apparently good authority, was much too high; and he could not make the process commercially successful.

Estimates of the gold content in sea water vary greatly, depending in part on the locality where the water is secured. There is some evidence that the water from the deep sea contains more than from the surface, but on the average there is something like a few parts per billion. The metal has been extracted, but the cost, at best, is about five times that of the value of the gold recovered.

In an attempt, by usual means, to electroplate gold out from sea water, it fails to form in a solid crystalline mass at the cathode, the negative electric terminal. Instead it precipitates to the bottom as a fine powder, in colloidal form. If an inexpensive means could be found to convert the colloidal into crystalline gold, the problem might be solved.

Dr. Colin G. Fink, of Columbia University, has worked on this subject, and has found a way of making the gold deposit as a solid. This is done by rotating the cathode at high speed. But the process requires more complicated equipment, more current and more expense, so it is still unfeasible commercially. However, Dr. Fink's studies have also revealed more about the way gold deposits out of solution. Even when the crystalline metal is formed, it goes through a colloidal step which previously had

not been detected. So, as our knowledge increases, we may yet come to gold from sea water—if indeed we want any more than we now have. But doubtless other important results will follow from these experiments, perhaps helping to obtain from the ocean metals of more real usefulness.

XII. *The Magic of Glass*

It is a curious fact that one of the very oldest of man-made materials should today be perhaps the chief characteristic of "modern" architecture. In many of these "functional" buildings the extensive use of glass is a most distinctive feature. Whole walls are made of glass bricks, doors are made of heavy sheets of glass without any metal edging, windows cover large openings and are often curved to conform to the line of the structure, while in the interior furnishings tables may be made of glass. If the building is modern, it is probably air conditioned; walls must be insulated against heat, and perhaps glass fiber performs this job, while the same fiber may even be woven into curtains and decorate the various rooms.

Yet the history of glass goes back so far that no one knows who discovered it. Perhaps, as Pliny relates, it all began some five thousand years ago when pieces of limestone and natural soda were accidentally used around a campfire on an open beach, and the chemicals reacted with the sand to produce glass. Or more likely it started, perhaps by an analogous process, in some Neolithic cave as long as ten thousand years ago. Indeed, glass was used even before that, for there are natural glasses, of which obsidian is the best known. Primitive men used this for arrowheads and knives, as well as for decoration. They did not use it for most of the tasks in which we employ glass, however, because obsidian is black, and not transparent.

Glass bottles for perfumes and other purposes were made in ancient Egypt, and some are preserved in our museums. In Rome too fine glass was made, and, at about the beginning of the Christian era, the secret was found of making glass transparent and clear. This art the Italian workers brought to its

height in Venice during the sixteenth century. Incidentally, there is a word often used in our language which goes back to the Italian glass makers. It is the word "fiasco." In those days, the making of glass was largely a process of trial and error, for the scientific controls of the twentieth century were still long in the future. But when an Italian glass blower got some glass that was not good for other purposes, he could still make it into a flask—a "fiasco"—for wine. And so now when something we plan turns out badly, we also say that it is a fiasco.

Soon after the first English colonists arrived in Jamestown, the first glass factory was established in America. This was in 1609; and in the first cargo exported to the homeland, some of the colonial glass was included. Mostly the Virginians made bottles, beads and trinkets to barter with the Indians. This factory lasted only a few years, and a second, established in 1621, was similarly short-lived. By the time of the Revolution, however, many glass factories were in operation, and in still more recent years a number of the fundamental advances in glass technique have come from American researches.

With many of the products that are described in this book, such as rubber, gasoline and explosives, it is possible to tell the chemical formula; but this cannot be done with glass. Actually glass is a liquid, though a rigid one, and has no regular atomic pattern, repeated over and over again. The best we can do is to say that a typical composition of glass contains 100 parts of sodium oxide, 67 parts of calcium oxide and 452 parts of silicon dioxide. However, physicists have determined something about the generalized arrangement of the atoms. It seems that each silicon atom is at the center of a tetrahedron (a triangular pyramid, having four faces and four corners) with an oxygen atom at each corner. Then each of these oxygens in turn has a second silicon atom, which is the center of another tetrahedron, attached to it. That is, the oxygen really forms a corner of two tetrahedra, which may be nicely arranged in exactly opposite directions, or else may be twisted around so they almost touch. This is very different from the neatly arranged latticework of

atoms in a crystal, such as natural quartz. Glass is definitely a non-crystalline substance.

Edison's invention of the electric light in 1879, and its rapid development in following years, provided a great stimulus for automatic glass machinery, and a departure from the time-honored methods of making by hand such things as bottles. In the hand process, a long blowpipe was dipped into a pot of molten glass, the drop that adhered was inserted into the top of a mold, and the glass blower blew. Mighty lungs were a requisite for such a profession. The soft glass filled up the mold, it was opened, and the bottle was the result. The first machines followed more or less this general technique, but in 1899 appeared the first conception of the Corning fully automatic machine for thin-glass objects, such as electric-light bulbs, thin tumblers and Christmas-tree ornaments. This, which was a complete departure from the old practice, permitted great speed in operation and enabled the glass manufacturers to keep up with the demand that was growing so rapidly for this new source of light—a speed which the bottle machines could not approach.

From the furnace into the automatic machine comes a one-inch stream of melted glass which passes between rollers that flatten it into a ribbon. In one of these rollers is a depression, and every time the ribbon comes against this a lump, or "biscuit," is formed. The ribbon passes to a moving belt with regular openings an inch or more in diameter; and it is timed so that each biscuit comes over one of the holes. Still soft, the glass in the biscuit sags through the hole, making a pear-shaped drop roughly the size and shape of the finished bulb. The drops grow longer. Then molds, lined with wet charcoal, close about them. To prevent marks from showing, the molds rotate around the glass drop, the water on the charcoal being turned into steam

by the heat so that there is actually a cushion of steam between glass and mold. Next, the nozzle of an air pump is applied from above to each embryo bulb, and air is blown in to make it fill out to the proper shape. At the end of the line the molds open, the bulbs are knocked off and pass to ovens where the temperature is gradually lowered. That is, the bulbs are annealed.

The speed of such machines is unbelievable. Perhaps it took you a minute to read the foregoing two paragraphs. In that time, one of these machines would turn out from 400 to 600 bulbs; and they have been operated as fast as 700 per minute. One might wonder what happens to the rest of the glass ribbon, the connecting portions that were not formed into biscuits. They are not wasted; they just go back to the furnace as scrap, to be melted over again. Bulbs that may be defective, or which are accidentally broken, can be salvaged in the same way, for these processes use more than 50 per cent of "cullet," as the scrap glass is termed. It is largely through such efficiency of production that a 60-watt Mazda lamp, for instance, which cost originally \$1.75, and 40 cents in 1915, can now be purchased for less than 15 cents. Once the automatic bulb machine was thought to have thrown men out of employment. Instead, by making lamps and radio tubes so cheap and plentiful, it has made many new jobs.

Glass is not a single material, like, let us say, iron, or aluminum. Rather it is a class, for glasses differ just as do metals. Some glasses are as dense as cast iron, while others are lighter than aluminum. Other important properties vary just as widely, and the compositions are very different.

Generally the job of glass is to transmit light; but by varying the composition the particular wavelengths, or colors, that it lets through can be selected as desired. It can be made to transmit ultraviolet rays, which are invisible. It can be made to cut off the shorter, harmful, ultraviolet rays, yet transmit the longer

ones that are beneficial. Bulbs for X-ray tubes can be made out of two kinds of glass. One lets these still shorter wavelength radiations through in the desired direction, while the other, constituting the remainder of the tube, stops them and protects the operator. And for skylights and windows there are glasses that cut out infra-red or heat rays, yet allow visible light to pass freely.

Though we think of glass as something that is easily broken, some varieties have strength comparable with steel, and others can be hammered, or bent, or exposed to heat and cold without damage. Much of this is owing to the work of the Corning Glass Works, which produced the first of its famous Pyrex glass in 1915. This was accomplished when it was found how to make a glass which varies only slightly with changes in temperature; that is, which has a low "coefficient of expansion." For Pyrex glass this is about a third of the coefficient for ordinary window or bottle glass, and that makes the difference. Glass is a poor conductor of heat. Consequently, if you have a thick piece, and heat is applied to the surface, the outside will expand, yet poor conduction will prevent the interior from heating as quickly, so the inside will not expand as much. If the change in size of the outer part is too great, the glass will crack. In the Pyrex glasses, the expansion is too little to cause such cracking.

Quartz, which is pure silicon dioxide, has a very low coefficient of expansion, and has been used for scientific and chemical apparatus, such as tubing, breakers and flasks. It also has strong resistance to chemical attack. However, it is expensive, and since its properties are approached by the properties of Pyrex, that glass now finds extensive uses in industry and laboratory, as well as for casseroles and pie plates in the home.

A further improvement, which brought glass even closer to quartz, came in 1939 when the Corning Glass Works introduced "shrunk" glass, under the name of Pyrex "Flameware." The older Pyrex cannot be exposed to an open flame without cracking, but this can be. Almost unbelievable demonstrations are

made of its resistance to temperature differences. It can be heated to redness, then plunged into ice water without cracking, or a dish of the material may be placed on a piece of ice and molten iron poured into it, again without damage.

This was a result of fundamental research into the properties of glass, made at first without any particular commercial application in mind, other than the knowledge that the more that was known, the more likely it would be that useful new developments might be made. In order to make glass strong, it is the usual practice to anneal it; to cool it slowly, especially over certain critical temperatures. Then no strains are set up, such as might result if the outer part cooled more quickly than the inner. However, it was found that prolonged heat treatment, at the temperatures used in annealing, made some glasses very much less resistant to attack by chemical reagents and even by water.

A further study of this effect over a number of years showed that, with certain chemical compositions, the glass actually separates into two parts, or phases. One is almost entirely pure silica, which is the common name for the silicon dioxide that makes up most of quartz. The other phase contains boric oxide, alkali and other constituents. Since the latter is easily dissolved by acids it is possible to place the heat-treated glass in an acid bath, thus extracting the second part, about a third of the whole. Then the mass becomes a sponge of silica, with microscopic pores remaining where the acid has done its work. The silica is unaffected by acid. Full of holes, the object at this stage has a cloudy appearance. It can then be heated once more, and if this is properly done, the pores close, the entire object shrinks about 35 per cent, yet retains its original shape with remarkable fidelity. A pie plate, originally $10\frac{1}{2}$ inches in diameter, will thus shrink to about nine inches. Then it is practically pure quartz, and can be used on an open flame without cracking. These same advantages have made the material of importance to the chemist as well as the cook.

In direct contrast to annealed glass is the tempered glass used for doors, and other purposes where great strength in resisting blows, rather than extreme temperatures difference, is wanted. The process of making this is analogous to the case hardening of metals. First the glass is formed to the proper shape, then it is reheated to a temperature well above the annealing point. At this temperature it is suddenly exposed to jets of cold air, or it is immersed in oil, or in various molten salts. This forms around the article a skin of glass which is trying to expand, and which is therefore under constant compression, pulling against the tension of the interior of the mass. Though constant strains are set up, these are balanced by the tendency of the glass to hold itself together; and thus the strength of the glass is increased many times. Pieces of tempered glass can be hit with a hammer or bent considerably without breaking them.

A blow of sufficient violence, of course, will puncture the surface layer and even break tempered glass. Then its behavior is different from that of ordinary glass, for as the stresses are suddenly released, the article shatters into countless tiny pieces. Fortunately, these fragments are more or less rounded, and are not as dangerous as the sharp splinters of ordinary glass.

To make glass that will not shatter, safety glass has been developed. In one form, a wire netting is laid into the glass while soft, and this holds the pieces together even if the sheet breaks. But as it is desirable to maintain clarity, laminated safety glass is more common. The first laminated glass was made for decorative rather than safety purposes when an Englishman named Fullicks, in 1885, obtained a patent for cementing pieces of variously colored glass between two sheets of clear glass.

Laminated safety glass was invented by another Englishman, John Wood. In 1905 he was granted a British patent for a method of cementing a sheet of Celluloid between two sheets of glass, using Canada balsam as the cement. The plastic,

Celluloid, was transparent, yet it held the pieces of glass together if the sheet broke. Production started, but lack of demand made the venture a failure financially. In 1910 a process was patented using gelatin instead of Canada balsam as the adhesive, and the resulting material was produced in England as "Triplex" glass. During the First World War it was extensively employed for gas-mask lenses, airplane windshields and visors, and automobile windshields. Following the war, as closed automobiles became more and more popular, the demand increased, and finally the use of safety glass for automobiles was made mandatory in most of the United States.

Celluloid, or cellulose nitrate, has disadvantages, some of which have been mentioned earlier. For one thing, the ultraviolet radiation of sunlight makes Celluloid decompose; it becomes brown and separates from the glass, which then is no longer non-shatterable. Cellulose acetate has been used instead, and is better, since it is not as much affected by sunlight.

Modern high-test safety glass makes use of one of the newer synthetic resins; a vinyl acetal plastic, which has considerable flexibility, combined with transparency and great strength. It sticks firmly to glass without the use of an adhesive, and is unaffected by ultraviolet light or by considerable temperature changes.¹ Generally, the vinyl acetal resin is used between sheets of glass that are quite thin, not more than one-eighth of an inch—and this is done paradoxically, to make it easy to break. For then most of the energy of an object that hits it is taken up by the plastic rather than the glass. At a meeting held at the Franklin Institute, where this glass was introduced, Dr. Edward R. Weidlein, director of the Mellon Institute of Industrial Research, described its advantages in this way:²

We are all familiar with the fact that a baseball catcher pulls his hand back with the ball when he is catching a "fast one." This practice

¹ Glass made with this as an interlayer has come as the result of an effort by the Carbide and Carbon Chemicals Corporation, E. I. du Pont de Nemours and Company, the Libbey-Owens-Ford Glass Company, the Pittsburgh Plate Glass Company and the Monsanto Chemical Company.

² *Industrial and Engineering Chemistry*. May, 1939: p. 563.

is to decelerate the baseball over a certain displacement so that all its kinetic energy is absorbed over a greater period of time, with the result that there is less sting in the ball. The same phenomenon makes it less painful to land in a firemen's net than on a concrete sidewalk.

Similar conditions hold for safety glass. If the kinetic energy of a fast-flying object that strikes a piece of laminated glass can be distributed over a greater displacement, there is much less chance that the plastic interlayer will fail; moreover less damage is done to the object that hits the glass. This latter consideration is important if the object happens to be the driver or passenger in a car.

Theoretically, then, from the standpoint of safety alone, the ideal material for the construction of windshields and sidelights in vehicles would be a very elastic substance that would act more like a firemen's net than a piece of boiler plate in case of accident. Because such an elastic material has not been found that would be acceptable for use by itself, advantage had to be taken of the clarity and hardness of glass to prevent the plastic becoming useless by abrasion. Laminated glass can be rendered safer by decreasing the thickness of the glass and so decreasing the amount of energy necessary to break it before the flexibility of the plastic comes into play.

Among the latest wonders of glass research is one that you would hardly recognize as a member of this family. It is black, non-transparent, lighter than cork and it can be sawed or drilled with ordinary wood-working tools. "Foamglas" is its name, and it has been developed after several years of research by the laboratories of the Pittsburgh Corning Corporation, which is owned jointly by the Pittsburgh Plate Glass Corporation and the Corning Glass Works.

Chief use of Foamglas, which floats in water, is to replace such things as cork, balsa wood, cellular rubber and kapok as a filling for life preservers and life rafts. Not only did it help to relieve a shortage of these imported materials; it also is superior to them, since it is odorless, fireproof and vermin proof. It is even more buoyant than cork, which weighs 14 to 16 pounds per cubic foot, as a cubic foot of Foamglas weighs only ten pounds. This is about the same as average grades of balsa.

In contrast, ordinary glass weighs 150 to 175 pounds per cubic foot.

Similar to the way in which yeast or baking powder raises bread by the formation of small cells containing carbon dioxide is the way that this light-weight glass is made. A little pure carbon is mixed with ordinary glass. When heated to the proper temperature, gas is formed, and the glass is puffed up, so that its density is about a fifteenth of what it was originally. Very exact control of time and temperature is needed in the process to secure rigid slabs in which the gas-containing cells are uniformly small and sealed off from each other.

Not only does Foamglas replace cork as a buoyant element; it also is taking its place as an insulator against heat, in the cold rooms of dairies, meat-packing plants and breweries. Even solid glass is a poor conductor of heat, and in combination with the gas cells it forms a most effective insulator.

Probably the glass product that has the least resemblance to the familiar concept of glass as a hard transparent substance, however, is Fiberglas, which is used both in the form of soft wooly fibers for insulation of heat and sound, and as a beautiful silklike fabric, available in practically any color.³ Heat insulation on ships of the U. S. Navy in 1932 was one of the very first applications of Fiberglas, for it met the requirements of naval architects who had asked for a fireproof insulation "that would be light in weight and take little room so that it won't encroach upon valuable cargo space and add to the deadweight of the vessel. It must withstand salt water and salt atmospheres. It should not rot, or decompose or feed vermin. It should not absorb cargo odors and it can't cost more than present materials."

Merchant ships soon used it, too. Then it was applied in

³This was largely the result of work by Games Slayter, now director of research of the Owens-Corning Fiberglass Corporation, with the aid, among others, of John H. Thomas. In 1931 they succeeded in devising a practicable method by which glass can be drawn into fibers. Pilot plant operation demonstrated that this could be done on a large scale, and the company was organized in 1938 as a joint offspring of Owens-Illinois and Corning, both firms having shared in the development.

dwellings and other buildings, keeping heat outside during the summer, and inside in the winter. Fiberglas is also coated with an adhesive that catches dust. Then, boxed in cardboard frames behind grills, it forms an effective filter for heating, ventilating and air-conditioning systems.

It was in 1936 that fibers strong and pliable enough to be woven into cloth were produced, and this opened a whole new field for the material. The great advantages of such a fabric are that it will not shrink, stretch, rot or burn, is not harmed by moisture, and will not fade. This makes it advantageous for use as draperies, bedspreads and table cloths. Neckties too have been made from it. In tapes and braids, it was found to be an excellent electrical insulating material.

An interesting use for Fiberglas is as insulation in electrically heated diving suits provided in the U. S. Navy for deep-sea divers. Formerly divers were supplied with compressed air, the usual mixture of oxygen and nitrogen, when they were below the surface. Physiological experiments, however, proved that a mixture of oxygen and helium has many advantages, particularly in preventing attacks of the dreaded "bends." However, this mixture tends to make the divers very cold. As this reduces their efficiency, it is then necessary to provide them with diving suits which are electrically heated. For insulation, Fiberglas was found to be the only material that was completely safe.

In preparing Fiberglas, the original glass is molded into marbles, each weighing about a quarter of an ounce. Any with imperfections can be discarded, and those that survive the inspection are remelted. The furnace chamber has in its base many fine holes, corresponding to the spinnerets described in connection with synthetic fabrics. The filaments of glass that flow through these holes—perhaps 200 or more—are gathered into a strand by a high-speed winder. Instead of continuous thread fibers, they can be made in staple-lengths, running between eight and 15 inches, more than the lengths of the fibers in the best long-staple cotton. Either kind of glass fiber can be spun and woven on standard textile machinery. Fabrics from

continuous filaments are smoother and harder finished, but those from the staple-length fibers have greater bulk, which sometimes is desirable. The fibers are tremendously strong; in fact, their tensile strength is greater than that of steel.

To make heat insulation, the marble stage is not necessary, and the glass ingredients can be melted in larger furnaces. Just as in making the staple fibers, the threads of melted glass flowing through the tiny holes are caught by jets of steam. The resulting fibers gather on a moving belt, which takes them all, as an endless blanket, to the place where they are fabricated.

But, of all the parts which glass has played, the one in which it has had the widest influence is as optical glass. It has enabled the astronomer to see and photograph galaxies so distant that their light, traveling at a speed of about 11,000,000 miles a minute, takes 500,000,000 years to reach us. With the spectroscope, using glass lenses and prisms, attached to his telescope, he has analyzed the stars, studied matter under conditions of temperature and pressure that we can never hope to imitate on earth. From these studies he has learned facts that help him to understand the behavior of atoms even of terrestrial matter.

In laboratories that deal with more mundane subjects, too, the scientist acquires his knowledge by means of glass. He also uses the spectroscope to look into matter. Through the lenses of the microscope, he sees the minute structure of metals. When he wants to distinguish friend from foe, he studies germs and other organisms, some of which cause disease, while others are beneficial. He uses photographic lenses to form images which make records far more accurate than any drawing.

Two things can happen to a light beam as it passes from the air into glass and then out again, or from one kind of glass to another. The final path of the beam may be in a different direction from the one which it followed originally. This is called "refraction," and the ability of a glass to refract is measured by

its refractive index. But also a beam of white light may emerge as a spectrum, a rainbowlike range of colors. This happens because different colors or wavelengths, which make up white light, are refracted to a different degree. Long waves of red light are bent least, while the waves of violet, about four-sevenths as long, are bent most. Consequently, the colors are sorted out into a spectrum: red, orange, yellow green, blue and violet. This is called dispersion.

Because of this fact it is not possible to make a single lens, of only one kind of glass, which will give a perfectly clear image in white light. If it is focused to make the image of the blue rays sharp, the reds will be blurred. If the reds are focused, there is a halo of blue around them.

Sir Isaac Newton, who first studied the effect of a prism in making a spectrum, came to the conclusion that all kinds of glass varied in refractive index and powers of dispersion to the same extent—that is, any two glasses which differed in one would differ in the other quality too. But later, in 1729, an English barrister named Chester Moor Hall showed that Newton had been mistaken. By combining two lenses, one convex, the other concave, he produced an achromatic lens, one which focused all the colors at the same distance. The first, the convex, lens formed an image which would have the colors blurred. But as the light rays passed through the second, the concave, lens, the dispersion of that one acted in the opposite direction and brought the colors into line again, compensating for the effect of the convex element. The second lens introduced refraction in the opposite direction too, and tended to restore the light rays to their original line; but for the same amount of dispersion its refractive index was less, and it did not completely undo the work of the first lens in bending the rays and forming the image. The result was an image which was achromatic, or free from unwanted color. In 1758 an optician named John Dollond introduced the achromatic lens commercially, and he is often given credit, though wrongly, for its invention.

Different types of glass were available to these early opticians,

but the manufacture of modern optical glass, on a scientific basis, began in 1862 in Germany when Ernst Abbé, professor of physics at the University of Jena, began his collaboration with the Schott glass works in the same Thuringian town. Abbé also took over the small business of a microscope maker named Carl Zeiss, and, with the aid of the new type of glass, made this into one of the most noted names in optical manufacture.

Before Abbé's time only five or six elements were in general use, and from them were made two principal types of optical glass. One was called "crown," with lime; the other, termed "flint," contained lead oxide. But Abbé and Schott added about twenty-five new elements to those used. This gave them an enormous range of optical properties, which could be obtained as desired; and optical systems could be made which were free from many of the faults that were inherent in the earlier glasses.

A few years ago an American chemist, Dr. George W. Morey, of the Geophysical Laboratory of the Carnegie Institution of Washington, was granted patents on a series of glasses using still more elements, and someday these may prove as great a step forward as did Abbé's work. Dr. Morey makes use of rare chemical elements such as yttrium, lanthanum, columbium and hafnium, many of which are members of the "rare earth" group of elements. The great advantage of these glasses is that they have still higher refractive indices, yet with no more dispersion. Previously, the highest index that had been attained was about 1.75, while Dr. Morey has gone above 2.00. Only the diamond, with 2.41, has a higher index. The rights on this invention, which will give the lens designer an increased range of materials to work with, have been assigned to the Eastman Kodak Company.

Optical glass has assumed even greater importance with the entry of the United States into World War II. Fortunately, the work of World War I created an American industry which is able to supply our needs, and, as exemplified by Dr. Morey's

work, to give us new materials as well. Up to 1914 all our optical glass had been imported, mostly from Germany; and by 1917 the supply of glass which our manufacturers had on hand had been practically exhausted making equipment for the Allies. This meant that, when we joined them in 1917 and the demand increased still further, the supply ran out entirely. Citizens were asked, as in World War II, to lend their binoculars to the Navy, and to let the Air Corps have their large photographic lenses.

Even to make the pots in which glass was prepared, German clay was required because it was free from iron. Such a minute quantity of iron as a few tenths of one per cent will contaminate glass, reducing its transparency. Nine different kinds of glass, it was estimated, were needed to produce instruments which the government required, but only two had previously been made in the United States. According to Dr. Arthur L. Day, former director of the Geophysical Laboratory, who had a leading part in establishing an American industry, the making of optical glass had been largely a secret process. "At the time of the war," he wrote later, "almost no authentic information had ever been printed. In France, it was a Government monopoly; in England, practically so. In Germany, the industry was virtually concentrated in a single firm whose secrets were its own. Optical glass formulas were never allowed to become known even within the plant where it was made."

But dark though the picture looked, two groups were organized to study the problem. One, from the Geophysical Laboratory, worked with the Bausch and Lomb Optical Company in Rochester; the other, from the National Bureau of Standards, worked with the Pittsburgh Plate Glass Company. At the end of four months the Bausch and Lomb unit had started production, and by the end of 1917 its output was 40,000 pounds per month.⁴ After 1918 the work was continued, mostly by

⁴ Later the Spencer Lens Company, of Buffalo, which is now a division of the American Optical Company, was asked to tackle the problem. A glass-making plant was erected at Hamburg, N.Y., under Dr. Morey's direction.

Bausch and Lomb and the National Bureau of Standards, and substantial quantities of glass, of numerous grades, were manufactured for government requirements. So now we have both the knowledge, and the plants, to make glass for the many optical instruments needed for war.

Only in recent conflicts have these been important. Back in the Civil War, for example, cannon could not fire much farther than the gunner could see, and accurate instruments were not required. When the range of guns was increased to as much as fifteen miles, it became possible to fire beyond the horizon; and at this distance a slight error in aiming, which might only put the projectile a few feet away from its mark at a mile, would make it miss by many yards.

On the gun itself there now must be an accurate panoramic sight, which is an optical instrument. Lenses of aerial cameras take photographs to guide the gunners. Enemy aviators are trying to do the same thing, so there are anti-aircraft guns. The rapid movements of the planes make them difficult for the gunners to follow, but complicated pieces of mechanism, combined range finders and calculating machines, automatically compute the data for aiming the guns. Sometimes, by means of ingenious electrical controls, these are connected with the directing mechanism and automatically aimed.

In the airplanes, not only are there camera lenses but also optical bomb sights. To enable the pilot to tell where he is, from measures of the height of the sun and other celestial bodies, he has a special aircraft sextant, designed for rapid reading. On the sea there is the sextant used by the navigator, who has a little, though not very much, more time for his work than the aviator. There are the binoculars with which the officer on the bridge watches for submarines. A range finder on the ship tells the distance of an enemy, and on the guns, too, are optical sights. The periscope with which the commander of the submarine sights his prey, then aims his torpedo, is a most intricate example of optical science.

In an optical system such as a periscope, where there are many separate pieces of glass, a great deal of light is lost by reflection. When a light beam hits a glass surface, most of it goes through, but a small percentage is reflected. That is why, if it is very bright and you are outside, you may have difficulty seeing in a window. If there are ten glass elements (and many optical systems have even more), the few per cent lost at each one will amount to a considerable total and the brightness of the final image will be materially reduced—perhaps to a quarter of the original brilliance.

As early as 1892 H. D. Taylor, in England, found that lenses on which a film of tarnish had formed were not deteriorated but were actually improved, since the glass surfaces did not reflect so much light. And if the light is not reflected, it is added to that which passes through. Several scientists in the past decade have devised methods of giving glass such a film artificially. These have to be a certain thickness—just a quarter the wavelength of light—because light waves have to enter a polished surface slightly before they can turn around to be reflected, and in this space they do not have room to do so. Dr. Katharine Blodgett, of the General Electric Research Laboratory, was one of the first to make these films, another was Dr. John Strong, at the California Institute of Technology, and a third was Dr. C. Hawley Cartwright, at the Massachusetts Institute of Technology. Unlike the films used by Dr. Blodgett, which easily rubbed off the glass, Dr. Cartwright's films, made of the fluorides of lithium, magnesium, calcium and sodium, are more permanent; and a company was organized to apply these commercially.

Essentially the same method was adapted to large-scale work by Dr. C. W. Hewlett and C. N. Moore in the General Electric Research Laboratory; and it is now being used to treat the glass covers of many instruments, such as ammeters and voltmeters. This makes them much easier to read when they are mounted

on a switchboard, for there is no danger of the meters' indications becoming temporarily invisible because of chance surface reflections. Dr. Hewlett's method is to place the glasses in a clip, held by a magnet to the interior of a large iron sphere from which the air is exhausted. A tray of magnesium fluoride inside is heated, and when the salt evaporates it deposits on the cold glass surfaces. The time is adjusted to give the proper thickness. At first, the tray was placed at the center of the sphere, but it was found that uniform films were obtained only if the tray itself were on the surface of the same sphere as that formed by the glasses.

Dr. Blodgett showed also that chemical treatment of glass could produce a non-reflecting film. She used glass containing lead, some of which was leached out with nitric acid; a process somewhat comparable to that involved in the first stage of making shrunken glass. The film here seems to be practically pure quartz; at least it was found to have the same refractive index as quartz. Two scientists, Drs. Frank L. Jones and Howard J. Homer, working at the Mellon Institute under a Bausch and Lomb Optical Company Fellowship, studied similar methods and showed how the film could be baked after its application with considerable increase in its durability.

Toward the end of 1941, the Radio Corporation of America announced a method which had been developed in their laboratories by Dr. F. H. Nicoll, of exposing the glass briefly by hydrofluoric acid vapor. This etches the surface and leaves behind a thin film of calcium fluoride. This film, it is reported, is very tough; it can be washed with water and alcohol and heated to high temperatures without damage. Such glass will be useful in television receivers, where the pictures are painted with electrons on the face of a glass tube, over which is a glass protector plate, and then a mirror in which the picture on the tube is seen. Applying the film to these glass surfaces will cut down the loss of light, just as it will in a system of lenses.

Despite such advances as these with so old a material as glass, there is still room for much further progress. According

to Dr. Eugene C. Sullivan, director of research of the Corning Glass Works, where so many of the past developments have been made: "In the developments still hatching in the laboratories there is nothing to indicate an end in the unfolding of the mysteries of glass. The glassmaker still dreams of the value to mankind of an easily melted glass which could be machined in a lathe, which bent instead of breaking, and which in ordinary use had the strength of steel."

Perhaps that, too, will eventually come.

XIII. *Higher, Faster, Farther . . .*

From the ill-fated attempt of Icarus to the experiments about the beginning of the twentieth century by so distinguished a scientist as Samuel P. Langley, man dreamed of flying. Then, in December, 1903, the Wright brothers made their flight over the sandy beach of Kitty Hawk, pulled by a twelve-horsepower motor. In a second less than a minute they covered 850 feet—and attained a speed of about thirty miles per hour. From that beginning, in less than four decades, have come the long-range planes of today, able to carry heavy loads for thousands of miles, and the high-speed craft, reaching velocities of around 500 miles per hour. And if it be objected that unscrupulous men have prostituted these gifts, then think of the benefits that, in proper hands, they can confer on mankind in the future.

Research made possible the first flights and has been responsible for the advances since—advances which, impelled by war needs, have continued at a greater rate than ever. The Wright brothers performed research, with the use of gliders and models, in a crude sort of wind tunnel. Through such experiments they learned the secret of securing longitudinal balance, by warping the trailing edges of the wings in opposite directions. Such a control had been lacking in the models previously constructed, a factor at least partly responsible for their failure.

It was quite fitting that the "Jennies" and other biplanes of the days of World War I were called "crates." Blériot and other early designers, to be sure, had tried monoplanes, but it was difficult to give them adequate strength. After all, as a famous British aeronautical engineer, Dr. H. E. Wimperis, has pointed out, the biplane was simply an adaptation of the familiar girder construction with an upper and a lower boom. This was the manner in which engineers had been used to taking care of

structures which tended to buckle. It is small wonder that they applied the same ideas to aircraft.

That this type of construction, with the engine in between the wings, caused great air resistance, was relatively unimportant because of the low speeds of that era. But as speeds were increased by brute force—by simply raising the power of the engine—streamlining became essential. The single wing of the modern plane has an upper and a lower surface, so it differs materially from Blériot's monoplane; and these surfaces are connected by a girder structure. Actually what has happened, though, is that the upper and lower wings of the biplane have come closer together, and are joined at front and back by the closing in of the space between these surfaces, so that air is not disturbed by passing around the connecting members.

Since 1918, aeronautical designers have "cleaned up" the outline of their planes. Not only have unnecessary excrescences been eliminated; the ones that were once thought necessary are also gone from the plane in flight. For instance, a plane certainly must have a landing gear—it will not be of much use if it cannot come to earth and stop. But to get rid of it in flight modern designers have made it retractable. The wheels fold up into the wings, and are covered by a smooth door. It was also found that the rounded heads of rivets which hold the metal skin of the plane to the framework produced a noticeable drag—so they are now countersunk, leaving the surface entirely smooth.

In the Hall of Aviation in Philadelphia's Franklin Institute is an instructive exhibit which gives a good idea of why an airplane goes up. It shows a model wing, held in an air stream. In a row, around the top and bottom of the wing from front to back, is a series of small holes, each connected by a tube to a pressure gauge. Thus it is possible to see immediately the way the pressure or lack of it is distributed. As might be expected there is positive pressure below the wing, but there is negative pressure—suction—on the upper surface. The principle that causes this was discovered many years ago by the physicist Daniel Bernoulli: the faster air moves over a surface, the less

is the pressure that it exerts on that surface. So the aeronautical engineer gives the cross section of the wing such a shape that the air moving across the top has farther to go—and hence must travel faster—than that which moves along the bottom. Improvements have been made, but still further advances are in sight. It has been reported that engineers have now in the laboratory a new wing that will be twice as effective as the best of the older types.

2

There are two types of aircraft, often confused in the public mind, which do not depend at all on wings for their lift, though the Bernouilli principle is still involved. One is the autogiro of the Spanish inventor, Juan de la Cierva. The faster a wing moves, the greater is its lift. Consequently, a plane intended for low speeds—for private flying, for example—usually has wide wings, while a high-speed pursuit plane has them narrower. What de la Cierva did, essentially, was to put four narrow wings on a rotor so they could spin around. Hence their speed through the air is much faster than that of the autogiro as a whole.

In the first models no power at all was applied to the rotor, and, in order to give the ship enough lifting power to take off, it was necessary for the pilot to taxi around the field, pulled forward by the propeller which performs the same function as in any other aircraft. Later, to allow takeoff in a confined space, the rotor was connected to the engine, which could start it spinning; but after the ship was in the air the rotor was thrown out of gear and allowed to spin freely. The advantage of this type of craft is that, unlike the airplane, its lift does not derive solely from its advancing through the air. Even if the engine stops, the rotor still revolves—not enough to keep the autogiro aloft, but at least with sufficient lift to permit it to settle to earth slowly without a crash.

Though it looks something like an autogiro, the helicopter, which also has rotating wings, is entirely different, for the rotor

is continually driven. The rotor is a vertical propeller which pulls the machine straight up. Many unsuccessful attempts to make a helicopter fly preceded those of a few years ago which finally did it. In the United States, the first success was achieved by Igor Sikorsky, Russian-born inventor who has made his talents available to us for a number of years.

Several problems had to be overcome in making a successful helicopter. For one thing, there was torque, or the tendency of the whole craft to spin in a direction opposite to that of the rotor. This is a result of the same effect that makes a gun kick—the bullet is pushed forward, and the gun is pushed backwards. The engine tries to spin the rotor around clockwise, let us say, but it is also trying to turn the fuselage around counter-clockwise. On the ground it cannot, because of the friction between the landing gear and the earth, but in the air it can and will, unless something is done to prevent it.

One solution is to provide two rotors, turning in opposite directions. These may either be one above the other or side by side. But that introduces complexities; and so Mr. Sikorsky put on the tail of his craft another, smaller rotor, spinning in a vertical plane, and in a direction to counteract the effect of torque. He was able to dispense with a third rotor, or propeller, to provide a forward pull. Instead, means are provided for tilting the main rotor in any direction. Tilting it forward, the helicopter advances. By tilting it backwards, the machine is made to back; similarly, it can move to one side or the other, or hover perfectly still in the air, even when only a few feet above the ground. In fact, one of the startling demonstrations that Mr. Sikorsky likes to put on is to hold the machine at this altitude while a mechanic calmly walks over and changes the wheels of the landing gear!

For many helicopters, however, three inflated rubber spheres are used instead of wheels. These can be used for coming down practically any place—on water, on rough rocks, or on top of a building, since the takeoff and landing may be really vertical.

Like the autogiro, the speed of the helicopter is limited—

probably it could not do much better than a hundred miles per hour at best. But its great advantage lies in its ability to move through the air at much lower speeds, impossible for conventional airplanes. It is not likely to threaten their supremacy for long-distance travel, where speed is desirable; but the helicopter may well make feasible an aerial taxi service—taking an air passenger from the street in front of his home to the airport, for instance. And in addition it offers great possibilities as a private aircraft for individuals.

Most aircraft designers, especially those working on war planes, however, are still concerned with speed. Though actual records of the fastest are closely guarded military secrets, they have probably reached 500 miles per hour—well above the last official record, established in 1939 by a German flier, of nearly 470 miles per hour. No doubt, too, the latest ships can maintain their high speeds over considerably longer distances than the short courses over which such records were established. In attaining such results many different researches were combined. Not only were the outlines of the planes made smooth and streamlined—the metallurgist contributed the strong light alloys of which the framework and the shell is made. He also developed new alloys for the engine, which can be made light and strong, yielding a horsepower for every pound of its weight. The chemist contributed the 100-octane gasoline; and numerous special controls have been added to give accuracy and reliability.

Satisfactory operation of airplanes at great altitudes has become increasingly important, both for peace and war. Six miles up the air is steady, for this is above most of the weather, so cruising speeds of 300 miles per hour at such an altitude would be entirely practicable for commercial transport. For fighter planes, great altitude affords also the advantage that a pilot may be able to get above enemy craft. Such altitudes in-

introduce new problems, one of which has been effectively solved by the turbosupercharger. But let the inventor of this device, Dr. Sanford A. Moss, General Electric engineer, and winner of the 1941 Collier award for great contributions to aviation, tell its story. He says:

An airplane engine obtains its power from explosions of charges of gasoline and air, the major portion of the charges being air. The air is obtained by being sucked in from the atmosphere as the engine pistons move back and forth. At altitudes above sea-level the atmospheric air gets thinner and thinner so that the charges being sucked in become less and less as airplanes fly higher and higher.

During the last war it occurred to some engineers to *push* increased charges of air into airplane engine cylinders, rather than depend upon suction from the atmosphere. This was soon found possible, and so the supercharger came into use.

The modern supercharger has a rotary wheel, called an impeller, of the same general nature as the rotor of a fan blower. However, the supercharger impeller rotates at a very much higher speed and has a more complicated design than any ordinary fan blower. This supercharger impeller is driven either by gears from the engine crankshaft or, in the case of the turbosupercharger, by a turbine wheel driven by the exhaust gases of the engine. The design of the impeller and its casing, the means of driving, the multiplication of effect by having several impellers in combination, and similar items, are technical details which have been the subject of great research, but which need not here be elaborated upon. The net result is compression of the atmospheric air at any altitude, so as to deliver an increased amount to the airplane engine.

The effect of the supercharger in thus pushing an increased charge into the engine cylinder can be made of service in three ways:

First: By maintaining the charge at the same amount as it would be at sea-level, as an airplane engine flies at increased altitudes. Otherwise the engine power would decrease in proportion to the decreased air density, so as to cut the power in half at about 20,000 feet altitude, with greater decreases at higher altitudes.

Second: By increase in the amount of charge used by the engine at sea-level, so that a given engine will give an increased amount of power. This may vary from an increase of 25% or so for short intervals, to greater increases for longer times, depending upon the design details.

Third: By a combination of these two items, so that at all altitudes

an engine will give the same increased amount of power as was possible at sea-level.

During World War I, the possibilities of superchargers began to be developed, but none of them then reached actual use. After the war, supercharger research was continued, and about 1920 a number of sorts of superchargers began to be used to a small extent. This use increased to about 1925 when it began to be evident that the supercharger was worth serious attention. About 1930 practically all aviation engines had a geared supercharger built in as an essential part of the engine structure. Similar advances were made with turbosuperchargers driven by engine exhaust gases. About 1940 these turbosuperchargers were being used to a greatly increased extent in United States military planes.

Every advance in the use of both geared and turbosuperchargers, obtained by engineering research, and by a practical demonstration of the results of this research, has given an appreciable increase in engine performance. As is always the case with every sort of engineering research, this process will continue and new refinements, new extensions, and new principles will be introduced into the supercharging art. It seems certain, therefore, that supercharging of one sort or another will form a more and more important part of aviation progress, both for commercial and military airplanes.

The exact nature of these expected refinements and extensions can hardly be predicted at the minute. Furthermore, even if they could be predicted, they would not pass military censorship. But it seems certain that the progress which has been made, from zero in 1918 to the very great use of superchargers in 1942, will proceed to an accelerated extent in the next quarter century.

Of course, the supercharger is only one of the many sorts of things which are undergoing intensive development in aviation at the present time. All of these will result in increased performance of airplanes, and increased use, both from a commercial and military point of view.

Modestly, Dr. Moss's account leaves out the part that he himself played in this development. It does not tell how he was retired in 1938, to be called back two years later, nor how, in 1918, he hauled a Liberty engine to the 14,000 foot height of Pikes Peak and found that it yielded only 230 horsepower, instead of 350 as at sea level. But when the turbosupercharger was cut in, 356 horsepower was obtained. With its aid, in 1920, Major R. W. Schroeder established a new altitude record of

36,020 feet, to be broken the following year, by using the same device, by Lieut. J. A. Macready, with 40,800 feet.

More recently the turbosupercharger has made possible the work of the U. S. Army's "Flying Fortress," which can attain speeds of better than 330 miles per hour at heights of six miles or more while carrying a heavy load of bombs. This is above anti-aircraft-gun range, and is so high that the bomber cannot be seen or heard from the ground. The bombs can be dropped with considerable accuracy, thanks to the steadiness of flight at these heights, and the plane can be off before the interceptors have been able to climb to its level.

Like so many war-inspired developments, this too will have important applications in peace, as Dr. Moss intimated. Instead of bombs, commercial planes flying at such speeds and levels will be able to carry large numbers of passengers, great loads of aerial freight or large quantities of gasoline for long-distance non-stop flights. And to permit the crew and passengers to survive at heights of even ten miles, the sealed cabin itself will be supercharged, keeping the air pressure of much lower levels. Indeed, this was lately done with the TWA "Stratoliners" plying between New York and Chicago; civilian versions of the Flying Fortress.

It is not only the plane itself which determines its performance. Although, as planes become more and more reliable, they are able to withstand conditions disastrous for earlier models, weather is still a factor for lower-flying planes; and even the ships plying in the sub-stratosphere have to pass through these layers on their way up and down. Accurate forecasting enables fliers to know what conditions they may encounter; but still, as always, there is not much that we can do about the weather.

Fog is one of the greatest dangers to aviation, but inventive ingenuity has made possible looking through it; a necessary development, since it is hardly practicable to remove fog over

a large area. In small lots it can be removed. If, for example, the air is heated, the fine droplets of water of which the fog is made may evaporate. Or calcium chloride solution can be sprayed into the fog. This absorbs water from the air, which becomes drier, so the fog particles can evaporate without an increase in temperature. Intense sound waves have been used to precipitate smoke, and might do the same on some kinds of fog, by causing many droplets to coalesce until they are big enough to fall to the ground.

Aerial photographs from great altitudes have been made with infrared light, showing details hundreds of miles away as clear as those much nearer. Yet with ordinary light photographs the distance is completely obscured in haze. Such experiments have led to a common idea that infrared rays can look through fog. A device has been constructed for taking photographs on special film in infrared light and developing it immediately and automatically, with the thought that it might be placed on the bridge of a ship, so that the pilot could make port in foggy weather.

The main trouble is that infrared rays do not penetrate fog. As Dr. Sverre Pettersen, professor of meteorology at the Massachusetts Institute of Technology, said in a lecture to the Institute of Aeronautical Sciences: "There is no region of the radiant energy spectrum which will penetrate fog better than visible light. This result has been confirmed by direct measurement."

The common belief that infrared rays do go through fog better was based partly on photographs showing their superior penetration of haze, and partly on the misuse of a formula for the transmission of light through suspended particles. This formula applies only if the particles are of about the same size as wavelengths of light, which the haze particles actually are. However, fog particles are some five hundred times bigger—each about 0.06 inch in diameter—and light waves equally long would have to be used to produce an effect. But though waves

as long as this may penetrate the fog, they in turn are absorbed by the gases of the atmosphere; so their advantage would be destroyed.

But even though they cannot penetrate a dense fog, infrared rays have important possibilities. One is the detection at night of enemy aircraft—or ships—that approach in darkness and are not considerate enough to provide lights or to warn of their coming. Infrared rays are given off by any hot object. Hold your hand near a flat-iron that is in use, and you can feel them, even though you cannot see them, because they are made of waves too long for the eye to detect. The hot cylinders of an airplane engine, or the hot funnels of a steamer, give them off copiously. So does the mass of hot gases exhausted from either type of engine.

Since infrared rays are like light waves, they may be focused, either with lenses or with concave mirrors, and an image formed of anything which is emitting or reflecting them. Some means must be found to make this image visible, and fortunately there are several ways of doing it. One, devised by Dr. V. K. Zworykin of the Radio Corporation of America, whose work with the electron microscope will be described in the next chapter, invented a means of doing it with electrons. A lens forms an infrared image on a thin metal plate which is coated with a compound of silver, caesium and oxygen. Where the rays fall on such a film tiny bits of atoms called electrons are discharged. These in turn can be focused with an electron lens—one kind consists of a circular electromagnet—on a glass screen coated with a fluorescent material. This glows where electrons strike, and the picture then becomes visible.

A still simpler means of making visible an infrared image was invented by Roscoe H. George, assistant professor of electrical engineering at Purdue University.¹ His discovery grew out of the observation that certain substances, related to those with which the final screen of the Zworykin infrared telescope

¹ Rights on the U. S. Patent (No. 2,225,044) granted him in December, 1940, are held by the Radio Corporation of America.

was coated, are phosphorescent. That is, they continue to glow for a time after they have been excited with light either visible or in the ultraviolet range, the waves of which are too short to be seen. Electrons and X-rays can also excite phosphorescence; and phosphorescent materials store energy, then give it off again later. But if they are sprayed with infrared rays they give it off more quickly. That is, you can take a phosphorescent screen out into the sunlight, expose it, then bring it into a darkroom, and it will be seen to glow. But if, in that darkroom, you have a source of infrared and hold the screen in its beam, it glows more brightly, but for a shorter time.

In Professor George's invention, the idea is to focus the infrared rays from the distant source, such as the plane's exhaust gases, on a phosphorescent screen with a concave mirror. It operates like an astronomer's reflecting telescope. Inside the telescope is a source of invisible ultraviolet, which shines on the screen and makes it glow faintly. Where the infrared rays fall, it glows more brightly, and the image is made visible.

In the formal language of the patent specifications, the use of the detector was described thus:

The present invention is useful in ascertaining the position of airplanes at night . . . since a certain amount of infra-red light is radiated from the exhaust manifolds of an airplane engine and this infra-red light is sufficient in intensity to make the position of the airplane visible through the use of the present invention even though the airplane itself is invisible, when the present invention is not used.

Infrared rays will not penetrate fog, but ultrashort radio waves, many times longer still, will do so. There are various ways of producing such waves; one is with the klystron, developed in the physics laboratory of Stanford University by Sigurd and Russell Varian.² Another is the magnetron of Dr. A. W. Hull, of the General Electric Research Laboratory. These are of the order of frequency of 600 megacycles—or about 20 inches in length, far below any used regularly in broadcasting. They have many of the properties of light waves; they can be

² Further work with it has been done by the Westinghouse Company.

focused in a beam like that from a searchlight. And just as light waves are reflected and sent back, so these are reflected, particularly by a metal object such as an airplane.

It is by the use of such waves that, as the Roberts report revealed, the Japanese bombers that attacked Pearl Harbor on December 7, 1941, were detected when they were 130 miles away. It was not the fault of the apparatus that its indication was ignored. No present-day military device is kept more carefully secret than the details of this equipment, just what is in it, and how it functions. However, enough has been revealed from official sources to get a general idea of the fundamental principles. In February, 1941, for instance, a patent (No. 2,231,-929) was granted to Joseph Lyman of the Sperry Gyroscope Co. and, like all patents, was published by the U. S. Patent Office. "The novel indicator," the inventor stated in the specifications, "is adapted for use on aircraft either for indicating the direction of approach of other aircraft, to thereby prevent collision under conditions of poor or zero visibility, or for use on the ground as when locating aircraft for purposes of gunfire control, or for controlling aircraft landings from the ground, and for other purposes."

One form of detector which was suggested used a radio "searchlight." A motor would be arranged to move it around, and up and down, so as completely to sweep the sky. When it encountered some reflecting object, such as an airplane, the waves would be sent back and picked up by a receiver. The echo returns practically instantaneously; and it might indicate by an electron beam on the end of a television picture tube. The electron beam would keep in step with the swing of the searchlight, increasing in intensity and making a bright spot when the echo was heard. Thus, the position of the spot on the screen would show the direction of the plane.

Another form suggested by Mr. Lyman makes use of two sheets of radio waves. One would always be vertical, and would sweep around the horizon. The other would at one moment be horizontal, then would sweep up to a vertical position and down

the opposite side. The connections on this device would be arranged so that both sheets of waves would act together, and their intersection would take the place of the single beam in the other locator.

Though developed for wartime use, such a locator obviously has tremendous possibilities for peace-time flying. Already, in fact, the Bell Telephone Laboratories, in co-operation with United Air Lines, have devised a terrain-distance indicator. The ordinary altimeter, which simply measures air pressure, tells the height above sea level; but more important to the pilot is his distance above ground. Ships at sea make use of a sonic depth-finder to tell the distance to the ocean bottom—a series of sound waves are sent downwards and the time of their return measured. The terrain-distance indicator works in a somewhat similar way, but radio waves take the place of sound. It makes its measurements of time by the interference which the returning waves make with those starting off; and it is so precise that, from a mile high, the aviator can tell the height of a building below him.

With such an indicator pointed ahead, he would be warned of approach to a mountain side, for example. But if the plane has a radio detector aimed forward, he might be able to see the outline of the mountain, and even to find in a dense fog a safe opening between two peaks.

These are some of the possibilities of aviation in our post-war world. Thousands of men, and women too, are trained as pilots, or as operators of all these aids to aviation. Their equipment is ready, factories are turning out planes in enormous quantities; and certainly it seems reasonable to suppose that what aviation did in the 1918-1939 period of peace will be considered trifling compared to the developments that are at hand.

XIV. *The Age of Electrons*

It was in the year 1895 that a bearded German professor of physics at the University of Würzburg saw a shadow, which ushered in the age of electrons. This discovery by the Herr Professor made possible the first of a long line of practical applications for man's benefit, including such devices as X-rays, the radio, the electric eye, sound movies, and a host of others.

The shadow that Wilhelm Konrad Roentgen saw extended across a card coated with white material. Now there was no reason why a shadow should not have fallen across this card, except that there was no light to make it.

About a score of years earlier, Sir William Crookes in England had experimented with high-voltage electric currents sent through glass tubes from which the air had been mostly exhausted. Such tubes are still called "Crookes tubes." From one of the electrodes inside such a tube, he found, mysterious rays were given off. As these came from the electrode called the cathode, they were named cathode rays; and by an application of these, certain minerals sealed inside a Crookes tube were made to glow with beautiful colors. From a concave cathode the rays could be focused on a piece of platinum foil, which then glowed at red heat. A little "windmill" with featherweight vanes was set in rapid motion when the rays fell upon it.

To explain the rays Crookes suggested a "fourth state of matter," different from the known solid, liquid and gaseous states. The study of these effects became a most popular field of research, and many new facts were uncovered. Heinrich Hertz, better known for his discovery of the "Hertzian" waves which form the basis of radio, found in 1893 that thin pieces of metal such as aluminum, when placed in a Crookes tube, were penetrated by the rays. Philip Lenard, the following year, car-

ried this discovery further: he made an aluminum window in one of the tubes and obtained the rays in open air.

Roentgen was working along similar lines in 1895. In the course of his studies he had tubes of various kinds. Some were pear shaped, with the cathode at the small end. The rays were sprayed toward the large end, and they caused the glass to glow. To hide this glow, Roentgen had covered some of the tubes with black paper. Also he frequently used a piece of cardboard coated with barium platino-cyanide. The cathode rays that Lenard had obtained in the open air caused this chemical to glow with a greenish-white color.

On one memorable day Roentgen was working with such material. It happened that the iron rod of an apparatus support stood between the tube and the cardboard screen lying on the table. There, across the screen, extended a shadow of the iron rod, even though no light was shining on it which could cause such a shadow. Later, someone asked Roentgen what he thought when he saw this strange shadow. His answer expressed the true scientific spirit.

"I did not think, I investigated," he said.

As a result of his investigations over the next few months Roentgen was able, in December, 1895, to report to the Würzburg Physical and Medical Association his discovery "Of a New Kind of Rays," as he expressed it in the title of his paper. Not knowing what these rays were, he called them X-rays, "X" being the mathematical symbol for the unknown. Paper, wood, hard rubber, he found, were transparent to the rays; so were thin metallic sheets except lead, which was opaque, as were greater thicknesses of other metals. He recognized that these rays were not the same as the cathode rays, though they were produced when those rays struck the glass walls of the tube. Also, he found that other materials inside the tube, such as metal targets, acted as a source even better than the glass.

Photographic plates were affected by the rays, so by means of them it was possible to make radiographs. Since the bones are more opaque to them than the flesh, the X-rays gave a means of

recording on the photographic plate, as well as viewing on a screen, the skeletal framework of the body. With every well-equipped physical laboratory already provided with one or more Crookes tubes and the spark coils to make high voltage to run them, Roentgen's experiments were being repeated just as soon as the newspapers could carry the word to an excited world. And also, more than one physicist felt a pang of regret at the great discovery that he had missed. For example, Crookes himself had been troubled by a mysterious fogging of his well-wrapped photographic plates when he operated some of his tubes in their neighborhood. A prominent American physicist had even, inadvertently, made a radiograph several years before Roentgen's discovery.

This near-discovery came in the course of some experiments in photographic electrical discharges. Metal discs, connected to the source of high voltage, were placed on photographic plates, and in this work the American had the help of a photographer friend. One evening, after they were through experimenting, the physicist demonstrated to his friend some of the Crookes tubes in his laboratory. Near by lay the box of plates, the metal discs on top. When the plates were developed, it was found that they showed images of the discs—actually an X-ray picture, made through the cardboard box. But puzzled though they were, neither could explain what had happened. Not until Roentgen announced the discovery of X-rays did the physicist realize what a close approach he had made to achieving world fame!

At this same time many other scientists were hard at work on the problem of what the cathode rays really were. When, in 1897, J. J. Thomson, the young director of the Cavendish Laboratory at Cambridge University, demonstrated that the rays could be deflected both by electrical charges and by magnetism, it became evident that the rays consisted of streams of particles at least a thousand times lighter than the hydrogen atom. Since they came out of many different substances used as a cathode, it seemed as if they might be a common constitu-

ent of all these materials. Of all the elements, the atom of hydrogen was supposed to be the smallest, and, people believed equally firmly up to that time, the atom was a solid entity, incapable of further division.

Yet Thomson's results were confirmed by others, and the electron, as the new particle was called, took its place as a unit of which atoms are made. Though its size cannot be stated with certainty, crude assumptions lead to the conclusion that some twenty-five trillion would have to be lined up in a row to equal an inch.

Atoms have been pictured as being made up of electrons whirling in orbits around a central nucleus. Each electron has a negative electrical charge, and in the nucleus is a positive charge corresponding to each of the orbital electrons. This picture shows a strong resemblance to the solar system, with the planets moving in orbits around the central sun. There is another resemblance, too. Just as each planet is spinning on its axis, so the electrons are supposed to be spinning. A spinning electrical charge produces the effect of magnetism, and in the spinning of the electron we find the basis of magnetic effects.

So, all matter is made ultimately of electrical charges. But not only are there the electrons in the atoms. In a metal, for example—especially one that is classed as an electrical conductor, like copper—there are so-called “free” electrons floating around between the atoms; and these apparently are responsible for conduction of electricity as they flow along the wire.

All this seems of very little practical value, and one might sympathize with the wealthy donor of a physics laboratory in the early days who, when shown some of these electrical discharges, remarked, “How beautiful, and how useless!”

However, the clue to the utility of the electron goes back somewhat earlier, to none other than Thomas Alva Edison. In 1883, in the course of his experiments with the electric lamp, a blue glow appeared when he sealed a small metal plate in a

bulb with the lamp filament. A wire led from this plate to the outside. When the lamp was turned on, Edison found that there was, in addition to the current which he put in to light the filament, another and very mysterious current flowing between one of the filament wires and the wire from the plate. In other words, this current flowed across the evacuated space in the bulb. Thinking it might have some utility, he patented it; but the patent had expired before the effect was explained, much less applied.

After Thomson's discovery of the electron in 1896, it became apparent that this is responsible for the Edison effect. As a result of the heating of the filament, some of the electrons it contains are freed and float away. Since these electrons are the same agents that carry a current through a wire, it is not surprising that they can carry a current across the vacuum in the bulb. That is, a minute electron current can be detected between the plate and the positive side of the circuit which lights the filament. This, however, is very slight, and a delicate instrument is needed to measure it. If, on the other hand, a battery is connected in this plate circuit, a larger current flows if connections are right; and the stream of electrons may be made to serve as a switch. When the filament is cold, none flow—the switch is off. But when the filament is lighted the electrons start flowing—the switch is on. When a rheostat is connected to the filament circuit, so that it can be turned up and down, the electrons vary and the plate current changes in step with the current to the filament. That is, it does up to a certain point; for when the current is pulling all possible of the escaping electrons across the gap, saturation is reached, and no more can be carried.

It was stated that the battery, in the plate circuit, had to be connected the right way. The plate has to be connected to the positive pole of the battery—the other way will not work. That is, the discharge of electrons from filament to plate is a one-way street for electricity.

In the early radio receiving sets, crystal detectors were used,

consisting of a bit of galena, or some similar mineral, on which a thin wire, or "cat's whisker," lightly touched. This also limited the electrical traffic to one way. The electrical waves, vibrating back and forth, which came into the receiver from the antenna, were rectified, and only those going in one direction got through and operated the head phones which radio listeners of those days had to use.

As long ago as 1904 J. A. Fleming, an English scientist, applied the Edison effect in a rectifier tube. It was used for radio reception, and also in other electrical equipment that required it. For instance, the ordinary lighting circuit of our houses is alternating current; the direction of flow of the current changes sixty times a second. Often it is desirable to change this to direct current, with the flow always in the same direction. By using a single Fleming valve (as such a tube was called in England because it did to electricity what a valve does to a flow of liquid or gas) only current in one direction can get through. That flowing the other way is blocked and wasted; but by using two such valves, properly connected, the opposite flow can be turned around, and then the wasted half is utilized.

Such tubes, generally called "diodes," are widely used today for rectifying. But the familiar tubes in our radio sets are "triodes," at least, for they contain another very important element—the "grid."

This was the invention of another American, Lee de Forest, in 1907. Between filament and plate he inserted a small screen, or grid, of wires. This can be thought of as a Venetian blind. Positively charged, the same as the filament, the blind is open and electrons pass through freely. But if it is gradually made negative, this is equivalent to closing the blind; and the stream of electrons is reduced and finally stopped. Such tubes made possible a new function—that of amplification. A very small current on the grid can control the flow of a larger current through the tube and, because of the instantaneous response, the quickest variations in the grid circuit are immediately reflected in the flow from the plate.

However, such tubes were seriously limited. They had to be operated with a relatively low vacuum, otherwise they would not pass a current. And the voltage had to be low, not over thirty or forty, otherwise Edison's blue glow appeared; the tube became erratic in behavior and soon went bad. The generally accepted theory was that the filament would not emit electrons unless some gas was present; and that seemed to impose a limit.

Dr. Irving Langmuir, in the General Electric Research Laboratory, had other ideas. Already, for his experiments on the cause of the blackening of incandescent lamps, he had developed equipment that would give and would accurately measure a vacuum higher than had been reached before. So now he used it to investigate the way electrons come from a filament.

Langmuir discovered that a filament will emit electrons in the very highest vacuum; but these electrons give the actual space around the filament a negative charge. Since like charges repel each other, this space charge repels additional electrons, each of which also has a negative charge, and they are prevented from doing their task. Langmuir found that when a small amount of gas is present, the electrons knock off other electrons which were part of the gas atoms. The remaining pieces, or "ions," have positive charges and neutralize the interference of the negative space charge.

Having found the cause of the difficulty, Langmuir was then in a position to overcome it. The plate of the tube was placed as close as possible to the filament; then, by using a higher voltage than had been possible before, electrons were pulled across the space so quickly that they were not there long enough to produce a space-charge effect. He could use a high voltage because, with high vacuum, there was no longer a blue glow to set a limit.

This discovery made it possible for the first time to design and build tubes which could handle high power—tubes in which the feeble currents from a microphone, for example, could be amplified millions of times—built up to 100,000 watts, or even more, to be used in powerful short-wave radio transmit-

ters that send clear signals to distant lands. Radio broadcasting would not have been possible without the electron tube and this means of using high power; for the inefficient spark transmitters of the earlier days of wireless telegraphy are quite impracticable for faithfully reproducing voice and music.

What happens in transmitting tubes, some of which handle a quarter of a million watts of power, is comparable to an annoying prank you could play with the older telephone desk set with a separate receiver. When the receiver was held against the transmitter, there was an unearthly howl. Sound waves from the receiver fed into the transmitter, were carried, as electrical impulses, back to the receiver, started around again, and so on, building up the oscillations.

In a radio transmission tube, part of the current from the tube is sent back to its own grid, and analogous electrical oscillations are started which eventually travel out from the antenna of the station. Receiving tubes, some with even a fourth or a fifth element as additional grids, are used in modern radio sets. Constant research has shown how to get the greatest flow of electrons—by using, for instance, not a filament of one wire as their source, but a small nickel cylinder, coated with the oxides of barium and strontium. Inside the cylinder is a filament to heat it.

Many of the vacuum tubes used in present-day radio sets are made of metal instead of glass. However, glass is still needed inside to insulate the various wires. Research in the General Electric Research Laboratory made this possible by the development of alloys of iron, nickel and cobalt which expand when heated and contract when cooled at just the same rate as the glass. If the expansion and contraction rates were different, of course, a glass-and-metal seal that was tight when the tube was cold would loosen and let air in as it heated in use.

Perhaps the most amazing thing about the modern vacuum tube is the application of mass-production methods to its manufacture, to supply the millions that are needed annually at low prices. Today, for less than a dollar, it is possible to purchase

a vacuum tube which is far more efficient than one which cost many dollars only twenty years ago when broadcasting made its debut.

Another electron tube has found application in such varied tasks as controlling the lighting for a dance number on the stage of the Radio City Music Hall and welding the metal shell of a bombing plane. This is the thyratron. In one of its largest sizes, it will control 300,000 watts of power with less than half a watt applied to its grid!

Different from the thyratron, which contains gas, is the high-vacuum kenotron, which operates over a range from a few volts to several hundred thousand. Its chief application is in rectification—that is, in converting the alternating current produced at most power stations into the direct current needed for such applications as the operation of X-ray tubes. Even this does not complete the family, for there are also the pliotron, the magnetron, and hundreds of other types of electron tubes, each with particular applications.

Of particular importance is the photoelectric cell, which, in its various modifications, sorts cigars, makes sound movies and television possible, opens and closes doors in stations and restaurants, turns on lights in schools, acts as a burglar alarm, and measures the brightness of stars. Its story again takes us back to Heinrich Hertz.

In 1880 Hertz was engaged in experiments with electric sparks. These were high-voltage discharges across open gaps; and he was surprised to find that when an arc light was shining on a gap, the same voltage would cross a longer distance than it would in the dark. Some time later W. Hallwachs found that a clean zinc plate, connected to an electroscope—a device for detecting electrical charges—lost its negative charge when the arc light was shining on it. But the arc had no effect if its light had to pass through a piece of glass. Since it was known that the light of the arc contained ultraviolet rays, waves too

short to be visible, it seemed evident that they were responsible, and that, in some way, they pulled negative charges from the zinc.

It turned out that zinc, under the influence of light, emits electrons—"photoelectrons," they are now called. Metals vary in the extent of this electron emission. Caesium and potassium have been found to work especially well, particularly with visible rays of light. The explanation of the details by which the photoelectric effect takes place was of great importance in scientific history. It was given by Albert Einstein, and won for him the Nobel Prize in Physics in 1921. Even if he had never thought of the theory of relativity, this accomplishment would still be enough to give him a prominent place on the roster of great scientists. It confirmed the quantum theory, proposed earlier by Max Planck, which states that light, and other forms of radiation, do not travel in a continuous stream of waves, but in little bunches, or "quanta."

The modern photoelectric cell has a metal surface, coated with caesium or a similar metal, in a glass bulb which is evacuated or contains an inert gas. The metal surface is one of the electrodes to which connections are made, and the other is a metal wire. When light falls on the caesium, it becomes capable of liberating electrons. If it is connected with a source of current, electricity can flow in the direction that the electrons travel. The result is comparable to the original Fleming valve, where heating of the filament made the tube a conductor. In the case of the photocell, light falling on the coated surface has the same effect. As current from the cell may be rather weak, it is often fed into a triode, or even a series of them, or into a thyratron, to enable the photocell to control much larger amounts of power than it can directly.

A development of recent years is the electron-multiplier tube. Essentially, this is a combined photocell and multi-stage amplifier all in one glass envelope. The photoelectrons from the original sensitive surface strike a second plate, which is also an excellent emitter. Each electron striking it may release half

a dozen more. These strike a third plate, and again the yield is multiplied—hence the name of the tube. With as many as a dozen steps in a single tube, the amplification may amount to hundreds of millions of times.

For many purposes another form of light-sensitive device, called the photovoltaic cell, is used. In one form this consists of iron coated with a layer of selenium, and on top is a thin layer of gold. When light strikes, electrons pass from the lower to upper layers and there is a flow of current. Thus, these cells actually generate electricity without the need of an external battery. For this reason they are used in popular types of photographic exposure meter, such as the General Electric and the Weston. With enough cells, sufficient current can be generated to run a small motor. Perhaps the day will come when sun-drenched desert areas of earth will be covered with such cells, turning light into electricity for the use of the world.

For opening doors, as in the Pennsylvania Station in New York, a beam of light is sent across the passageway through which people must pass. This falls on a photocell, and the current, amplified, operates a magnet which holds down a little lever—a common device, called a relay. When the light is interrupted, the current stops, the lever is pulled by a spring, and it makes contact to close a second electrical circuit. This in turn operates the motors which open the door. The same method can be used to count the number of visitors entering a museum. In this case the lever, each time it is released from the magnet (or alternately, with a different connection, each time it is pulled toward it), operates a counter.

The device may even be made to exercise judgment! That is, it can count people going in, but pay no attention to those going out. This is done by two light beams, two photocells and two relays. The inner beam operates a relay which disconnects the counter, so if that operates first nothing happens. But a person coming in interrupts the other beam first, and the counter operates before the other beam is broken. Photocells have also been used to inspect cigars, oranges and a variety of other

things. The articles to be inspected pass on a belt under a strong light, which they reflect to a photocell. When one comes along that is too light or too dark, more or less than the normal light falls on the "electric eye." Either occurrence may operate the relay; and another lever, magnet-operated, kicks the offender aside.

Because the photocell is so sensitive, and because its current, proportional to light falling on it, can be measured so accurately, it has become a powerful aid to the astronomer in measuring the brightness of stars. Another astronomical use that is just beginning is in guiding star cameras on long exposures. On account of the changing path of the light through the earth's atmosphere, caused by irregularities of temperature, it is customary for an astronomer to sit constantly at such a telescope while a picture is being taken with an exposure, perhaps, of many hours. But experiments at the California Institute of Technology, which will operate the new 200-inch telescope to be ready in a few years on Mt. Palomar, indicate the possibility of doing this by photocells.¹

We have seen how light, and other forms of radiation, can set electrons into motion. The reverse process can take place, and moving electrons can start radiation. This, indeed, is what happens in the X-ray tube.

After Roentgen's discovery, scientists puzzled over the nature of X-rays. They suspected that they were similar to light waves but shorter, even far shorter than the ultraviolet. If such were the case, it should be possible to "diffract" them. This can be done with light, using a piece of glass ruled with thousands of parallel lines to the inch. It acts in a manner similar to a prism, and breaks up white light into the colored band of the spectrum. With the wavelength of X-rays so much less, the grating needed

¹ The use of photocells in television and in sound movies is described later, in connection with those topics.

to break them up and cause diffraction would have to be ruled with lines far closer than man could make.

But there proved to be natural gratings of the requisite fineness. Prof. Max von Laue in Berlin, in 1912, made the suggestion that regular layers of atoms in a crystal, such as diamond or rocksalt, might serve as such a grating. When the experiment was tried, shooting X-rays through a crystal to a photographic plate, spots caused by the diffracted rays were found around the central beam, and their position depended on the wavelength of the X-rays. This was using the crystal to study X-rays. About the same time Sir William Bragg, and his son Prof. W. L. Bragg, worked the other way and used X-rays to study the structure of crystals.

From this pioneer work of the Braggs came an entirely new means of determining the structure of matter. In many industrial laboratories today, X-rays are used in special X-ray spectrometers to look into the construction of matter; of alloys for bombing planes, of fibers of wool and other textiles, and even into the behavior of rubber and of lubricating oil.

X-rays, it thus turned out, are a form of radiation like light, which results when speeding electrons are suddenly stopped against a metal target. In early tubes the electrons were pulled from the cold cathode by the bombardment of positive ions. These ions were fragments of the molecules of the small amount of gas remaining in the tube, broken off, or "ionized," when the high voltage was applied. The rays were very erratic in behavior because of the difficulty in controlling accurately the minute amount of remaining gas. Then, in 1913, Dr. William D. Coolidge, at the General Electric Research Laboratory, invented the tube now almost universally used which bears his name. Gas is all but completely removed. Electrons are supplied not from a cold cathode but from a small glowing filament like that of an electric lamp. High voltage is applied, as in the old tubes, and these electrons are pulled along and thrown with great speed against a target of metal, usually tungsten, from which the X-rays radiate.

To get more and more penetrating X-rays, voltages were increased; but there proved to be a limit. If the voltage gets too high—up to several hundred thousand or more, far above that needed for ordinary medical X-rays—“field currents” appear in the tube. These are produced by electrons torn out of the cold metal. They make the tube erratic, may even cause its destruction.

Over a decade ago, Dr. Coolidge found that these field currents can be eliminated if the high voltage is applied in steps. Tubes were built in several sections, perhaps a hundred thousand volts being put into each one. If there are five sections each having this voltage, the electrons, after passing all the way through, will possess as much energy as if the total 500,000 volts had been applied at once.

Using this principle, about ten years ago Dr. Coolidge and Dr. Ernest E. Charlton developed equipment for 800,000 volts. It was made for a hospital, to give high-power X-rays for cancer treatment. The tube was 14 feet long and a foot in diameter. Because of its bulky high-voltage generator, a special building had to be erected to house it. Still bigger is a 1,400,000-volt X-ray outfit built by G. E. for the National Bureau of Standards, as shown in the illustration. And again electronic research, under the direction of Dr. Charlton, solved the problem of making million-volt X-rays portable. Paying tribute to him and his associates, Dr. Coolidge has said: “The research work involved occupied the full time of an average of six men for a period of four years, and this, starting of course not from scratch, but with full knowledge of the X-ray equipment of the prior art.”

Two developments were mainly responsible for the new unit. Enclosed X-ray equipment had previously used oil in the casing to insulate the parts from high voltages. Now it was found that Freon gas, developed for use in electric refrigerators and known chemically as dichlorodifluormethane, could be pumped in under pressure and was more effective. Also, a new type of transformer was designed by W. F. Westendorp. This is called the resonance transformer; it eliminates the iron core that nor-

mally forms the center of the coils of wire. With the core gone, the multi-section X-ray tube itself, 30 inches long and $3\frac{1}{2}$ inches in diameter, was placed in this central position, an advantageous one making for compactness and shortening the electrical connections.

A metal extension of the tube projects two feet from the cylindrical tank which holds the entire equipment, and from its end emanate the X-rays. Some shoot straight ahead, as from a gun, others are sprayed to the side. Ordinarily direct rays are used, but sometimes the side ones are more convenient. The snout can be placed at the center of a boiler and a series of radiographs, as the X-ray pictures are called, taken with a single exposure on a series of films all around the circumference. In this way the new apparatus speeds inspection of machinery parts. The million-volt outfit will radiograph through five inches of steel in two minutes. A tube operating on 400,000 volts, the next size smaller, requires three and a half hours for the same job. Even then, the lower power picture does not show nearly so much detail in the thicker sections.

When a steel casting is found to have a defect, such as an inclusion of slag, the radiograph shows its position; the casting is sent back to the foundry and the defect is chipped out. Then new metal is welded in and the part is again X-rayed. If satisfactory, the construction of the machine is completed.

Even on smaller parts, high-voltage is a help, as the tube can back away from the job and spray a large area with the rays. Don M. McCutcheon, in charge of the X-ray laboratory at the Ford Motor Company, found, with a heavy part destined for a large bombing plane, that at least six exposures were needed for each casting with 400,000 volts, while the million-volt machine completely X-rayed six entire castings at once! ²

² Million-volt X-rays were not developed because of urgent wartime activities, but their application has been speeded. A present-day parallel is seen to the way in which the last war made popular the general use of medical X-rays. They still were somewhat of a novelty in 1914, but doctors called to military service had to use them. They learned their advantages, and continued to use them in private practice after the war.

Not only are the X-rays used in this way, and for examining the structure of matter by means of the X-ray spectrograph; the electrons themselves have similar ability. For example, in the General Electric Laboratory, the Bell Telephone Laboratories and others, are used electronic-vacuum cameras that photograph the crystalline make-up of substances the thickness of which is measured in millionths of an inch. The camera is employed, for instance, to study deposits on the surface of metals, such as tarnish, polish, lubricants, and the first stages of corrosion. Where the X-ray apparatus works on thicker specimens, the electronic-vacuum camera supplements it by revealing the nature of thin materials in a record that shows a series of concentric circles—their spacing and position telling the scientist the arrangement of the atoms.

The camera in the G-E laboratory is a brass tube about three-and-a-half feet long, combined with a focusing magnet. A beam of electrons, with a 40,000-volt push, enters one end of the tube. The magnet focuses this beam on the specimen, which is suspended inside. Here the beam is "diffracted" and the electrons paint their picture on a sensitive photographic plate at the other end. The brass tube has to be evacuated—otherwise the electron beam could not pass through freely because of the collisions with air molecules. In sodium chloride—common salt—the layers of atoms are spaced one one-hundred-millionth of an inch apart. But the electron picture of this spacing shows a circle an inch in diameter.

It must not be supposed, however, that this gives a realistic picture of the arrangement of the atoms magnified a hundred million times. The resulting circle bears no resemblance to the appearance of the salt crystal. The effect is analogous to that, mentioned above, by which light is diffracted by a grating made of fine lines ruled on glass.

This electronic diffraction method represents a very rapid application of fundamental research. The quantum theory, and the phenomena of photoelectricity, had shown that light, once thought of as a wave motion, had some of the properties of

separate particles. In 1925 C. J. Davisson and L. H. Germer, at the Bell Telephone Laboratories, showed the reverse. They demonstrated that electrons, which had seemed to be separate particles, have many properties of waves. At about the same time at Cambridge, G. P. Thomson, brilliant son of J. J. Thomson who discovered the electron, showed for the first time that electrons could be diffracted, another demonstration of their wave nature. It was from this pioneer work that the electronic-diffraction camera has developed as a practical tool.

However, though this does not give an actual picture of the atoms, minute substances, even very large molecules or groups of atoms, can be reproduced, magnified, by electrons. Many industrial laboratories are now equipped with the electron microscope, using it for the examination of metals, of dust or smoke, of biological agents, and other substances. Where two thousand diameters represents the practical limit of the old-style microscope, using light, which was the best available until a few years ago, the electron microscope goes many times higher and permits the examination of details fifty times as fine.

Early experimenters with cathode rays, before the electron had been heard of, found that the beam of rays could be bent, either by a magnet, or an electrostatic field around charged plates, much as a prism bends a beam of light rays. And just as a prism can be elaborated into a lens which will focus light rays to give a sharp image of a scene in front of a camera, so can electromagnetic, or electrostatic, fields be made that will focus a beam of electrons.³

The RCA instrument was the first to be placed on the American market. The electrons, originating from the familiar hot filament, are speeded on their way with a 60,000-volt kick. This gives them enough speed to penetrate the specimen, which is

³ In the electron microscope made by the Radio Corporation of America as the result of researches by Dr. V. K. Zworykin and his associates, the focusing is accomplished by electromagnets; other types use the electrostatic focusing.

very thin—perhaps about $\frac{1}{100,000}$ inch. Of course, as with the diffraction camera, it is necessary to keep the apparatus exhausted of air. This imposes some limitation, though not a serious one, on the nature of the specimens, since they must survive in a vacuum. Also, they must be at least partially transparent to electrons.

The course of the electrons is exactly similar to that of light in the ordinary microscope. Coils of wire serve the same function that lenses serve with light. A condenser focuses the beam on the specimen. The beam spreads, another electron lens picks it up and forms a somewhat enlarged image. Another lens picks up the electrons from this intermediate stage and focuses them again to form the final image, with magnification as much as twenty thousand diameters. This can be seen on a fluorescent screen, which converts the electron image into one of light. Or the image can be formed on a fine-grain photographic plate. From such a plate, when developed, prints greatly enlarged can be made, to bring the total magnification of the final micrograph to 100,000 times or more.

In reporting recently to the American Chemical Society, Dr. Zworykin of RCA thus summarized the accomplishments of the instrument:

To begin with, attention was naturally focused on bacteria, well-known and dreaded disease-causing micro-organisms. A "rogues' gallery" prepared with the electron microscope revealed a host of new detail which it will take years to interpret. As an early find, the blood-corpuse-dissolving streptococcus haemolyticus was shown to be encased in a sturdy membrane which survived evacuation and electron bombardment. In the case of diphtheria organisms chemical reactions with tellurium salts could be observed with the individual cells.

The electron microscope proved to be especially well adapted for the study of the viruses, border-line organisms too small to be seen with the ordinary microscope, which are responsible for various plant and animal diseases. Some of these, like the tobacco mosaic and cucumber mosaic viruses, were found to be rod-shaped, others, as tomato bushy stunt and tobacco necrosis viruses, essentially spherical. It was possible to study in detail their mode of aggregation, as well

as the action on them of chemicals and of the antibodies generated by animals to protect themselves against virus diseases.

In the field of the higher animals, studies have been made of chromosome strands contained within reproducing cells. These are known to be the seat of the genes, or factors determining the inheritable characteristics of the organism. Thus here the electron microscope may eventually aid in unravelling some of the secrets of heredity.

Turning to applications in the inorganic world, the electron microscope is particularly effective in the study of finely divided matter, such as the carbon black as rubber preservative and as a constituent of various inks. Particle size and size distributions of carbon blacks of different origin are readily determined with the electron microscope. With pigments the shape of the individual particles and their consequent mode of aggregation and covering power are other important factors which are revealed by the new instrument.

These characteristics also govern the effectiveness of many insecticides and chemical absorbing agents. All of these have been subjects of study with the electron microscope. Even in the case of substances as homogeneous as modern plastics, this powerful instrument has been able to reveal minute structural detail invisible up to now.

Finally the electron microscope has been put into service for the study of the surface of metals and other bulk materials. For this purpose a plastic replica of the order of $\frac{1}{100,000}$ inch in thickness is made of the surface. This is examined as any other transparent object, the degree of transparency being determined by the thickness of the replica at any point and, hence, by the contours of the original surface. In this manner metallurgists have followed out the important problem of the constitution of steel beyond the point where the metallographic light microscope could give information.*

But of the many accomplishments of the age of electrons, there is still another—the most widespread of all. This is radio. Its story will be told in the next chapter.

* A simplified method of obtaining a plastic replica of a metal surface for examination with the electron microscope has been devised by Vincent J. Schaefer and David Harker, of the General Electric Research Laboratory. It is an adaptation of the former's work in preparing replicas of snowflakes and other short-lived forms. The illustration shows a specimen of carbon steel in a photomicrograph (taken with light) at 2,000 magnification, and an electron micrograph of a plastic replica at 28,000 magnification.

XV. *Radio Today and Tomorrow*

To many of us, radio began in the early twenties, when we sat with a pair of head-phones clamped to our ears, carefully tickling a galena crystal with a cat's whisker in the old crystal set, trying to pick up the feeble whispers of voice or music from one of the early broadcasting stations. But ten years before that a handful of amateurs, with noisy spark transmitters, were talking back and forth to each other by "wireless"; and only ten years before that, in 1901, Guglielmo Marconi had sent his first signals between Cornwall, England, and St. John's, Newfoundland.

Thus radio actually began at the dawn of the twentieth century. Like other potential scientific advances, it had a great development during World War I; and that set the stage for the inauguration of broadcasting in the post-war period, beginning, as far as the United States was concerned, with KDKA, the Westinghouse station in Pittsburgh, which started transmission in 1920. In earlier days, the inability of the wireless to confine its message to a selected receiver had been thought a disadvantage, but this very factor now made it possible for radio to play a role that was truly new, in permitting a speaker to be heard by millions, regardless of physical or artificial boundaries that might intervene. Even today we have hardly begun to realize the full implications of this medium.

Although crude radiotelephony had been accomplished with the spark transmitter, the first regular broadcasters made use of the electronic tubes described in the preceding chapter. And soon after their beginning, and as commercially built receivers largely replaced the home-made sets of the early days, tubes were used for reception as well, and the crystal receiver became obsolete.

Those first sets used largely the regenerative circuit which Edwin H. Armstrong had invented in 1912 while he was an electrical-engineering student at Columbia University. But they also acted as rebroadcasters of low power, and tended to produce interference, in the form of squeals, in neighboring receivers tuned to the same frequency. In later years they were extensively replaced by the superheterodyne circuit, also invented by Major Armstrong, who by that time had served in the U. S. Army Signal Corps. Now he is professor of electrical engineering at Columbia.

If two whistles, of nearly but not quite the same pitch, are blown simultaneously near each other, the two sets of sound waves combine to produce beats. An analogous effect is seen when one looks through two parallel picket fences and sees a series of light and dark bands, which are considerably farther apart than the stakes in either fence. At one position, several openings in one fence line up with those in the other and there is a clear space. But a little farther on, the pickets in the distant fence are behind the openings in the nearer, and then there is a dark region. So it is with sound. First, the waves of one sound will combine with those of the other to reinforce them, as the two sets are in step. But because they are not the same length, they soon get out of step, and then one set cancels the other. This makes a set of waves farther apart—that is, a sound of lower pitch than either one of the originals.

A heterodyne circuit combines the vibrating current as received through the antenna with a current of a different frequency set up in the receiver, in such a way that beats are formed which bring the high frequency down into the "audio" range—to within the limits of sensitivity of the human ear. But the superheterodyne produces beats which are still above the audio frequency range, so there is a second detector tube which brings it down the rest of the way. Such a circuit is used widely even though the manufacturers must be licensed under the Armstrong patents.

In 1939 Major Armstrong contributed another invention,

which may in the future prove just as popular as the superheterodyne. This is frequency modulation, commonly called FM, which eliminates the old trouble of static, and also permits many stations to broadcast on the same frequency.

Your present radio set is probably one which uses the older kind of transmission, that of AM, or amplitude modulation. About 50,000,000 of these, it is estimated, are now in use in the United States. In the AM transmitter special equipment, at the heart of which is an accurately ground crystal of quartz, keeps the station broadcasting on the frequency (or wavelength) to which it has been assigned by the Federal Communications Commission. That government organization constantly checks all transmitters, to be sure that they keep to their frequencies; and if they deviate, a reprimand or even a cancellation of their license will be the result. In contrast to this, the FM transmitter continually changes frequency, not haphazardly, but in a definitely regulated manner; and this variation is what carries voice or music to the receiver.

A good AM receiver tunes very closely. That is, when you tune with the dial, and not with pushbuttons, you have to set the indicator very accurately. If you move it a little one way or the other, the music varies both in intensity and in quality as you do so. Now, if the engineer in control of the broadcasting station were to vary the frequency of transmission while you are tuned to his station, the result would be similar. It is hardly difficult to imagine a station broadcasting a steady note, but varying its frequency in such a way that the receiver gets it first loud and then soft, and even reproducing speech and music in this way.

Essentially, this is what happens with FM broadcasting, but entirely different circuits are required both in transmitter and in receiver to take effective advantage of frequency modulation.

Suppose we have an AM station with a frequency of 810 kilocycles, that of WGY. This means that the "carrier wave" which is radiated from the station's antenna is vibrating 810,000 times every second. When your receiver is tuned to this station, it

picks up this carrier, but the vibrations are much too rapid to be heard. It has to be modulated, and this is done at the transmitter. The circuit from the studio microphone regulates the height, or "amplitude," of the individual waves, though it does not affect the distance between one wave and the next. In the detector tube of the receiver, the carrier frequency is eliminated, and the variations in amplitude are made into a vibrating electrical current which, after being amplified some more and being fed into the loud speaker, will set up air waves that reproduce the original sounds.

Lightning flashes are natural broadcasting stations, but, entirely disregarding the rules of the FCC, they do not keep to a single frequency. Instead they send out waves of many frequencies, so one of them will be the same as that of the station to which you are listening. Hence they join with the waves from the broadcaster, enter the set together, and give you a crash of static in the loud speaker. Electric razors, vacuum cleaners, and other kinds of electrical equipment behave in similar manner. As a result, with AM broadcasting there is no satisfactory way of eliminating static, since the waves that cause it are the same as those which you want, and one cannot be eliminated without the other. Only by getting close to a powerful station can the broadcast signal be made so strong that it actually overrides the static.

With the FM station there is also a carrier wave. Since these transmitters have been assigned to the short waves, or high frequencies, the carrier is much more rapid than for the ordinary broadcasters. W85A, at Schenectady, for example, has a frequency of 48,500 kilocycles; that is, it vibrates 48,500,000 times every second. When the station is on the air, but while no signal is coming to the transmitter from the studio, the FM carrier wave is no different from that of an AM station under comparable circumstances.

When someone speaks into the studio microphone the effect on the carrier is very different; for now the amplitude of the waves remains the same but the distance between them, which

determines the number that can occur in a second, changes. Frequency modulation stations are separated by 200 kilocycles; and this, with 50 kilocycles of clear space between adjacent channels, means that our station assigned to 57,700 kc will swing 75 kc either side of that mean, covering a range of 150 kilocycles. Thus the FM receiver not only has to be able to time these short waves (or high frequencies), but must also be able to tune in the signal over this range. In the AM stations, on the other hand, the separation between channels is only ten kilocycles. Consequently, a set must be designed to tune in a much narrower band—otherwise it may pick up two stations at once.

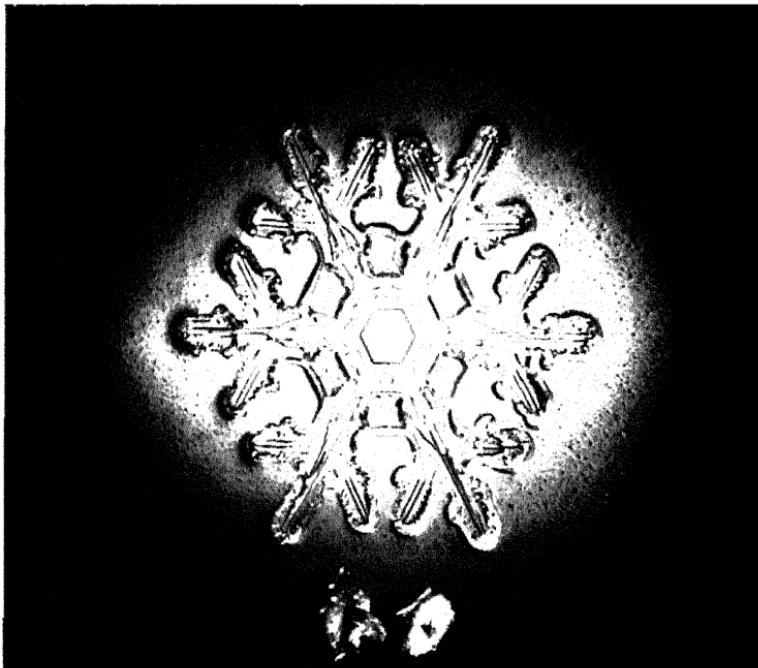
Now let us see what happens to static when it tries to interfere with FM broadcasting. Perhaps there is a flash of lightning, and the waves of the static join with the broadcast wave, producing a variation in amplitude as well as in frequency. This is picked up by the aerial, and the static actually gets into the receiver. But in it there is a "limiting circuit." This, in effect, chops off the tops and bottoms of the waves by the use of electron tubes, making the amplitude constant again before the detector tube gets the incoming signal, so it has no knowledge of the static. The detector circuit now converts the changes in frequency into changes in amplitude; and from there on to the loud speaker, the process is just about the same as in older broadcasting.

Because AM receivers, even if they could tune the short waves broadly enough, lack the limiting circuit and the converter to change frequency variations over into changes of amplitude, they will not tune in frequency modulation. But "translators" are available commercially. These are FM receivers without the final audio amplification and loud speaker of a complete set. When fed by the proper antenna, and plugged into the AM receiver like a phonograph attachment, they make use of the same amplifiers and loud speaker. Also, combination sets have been made with translator built in, which can be used both for FM and AM reception.

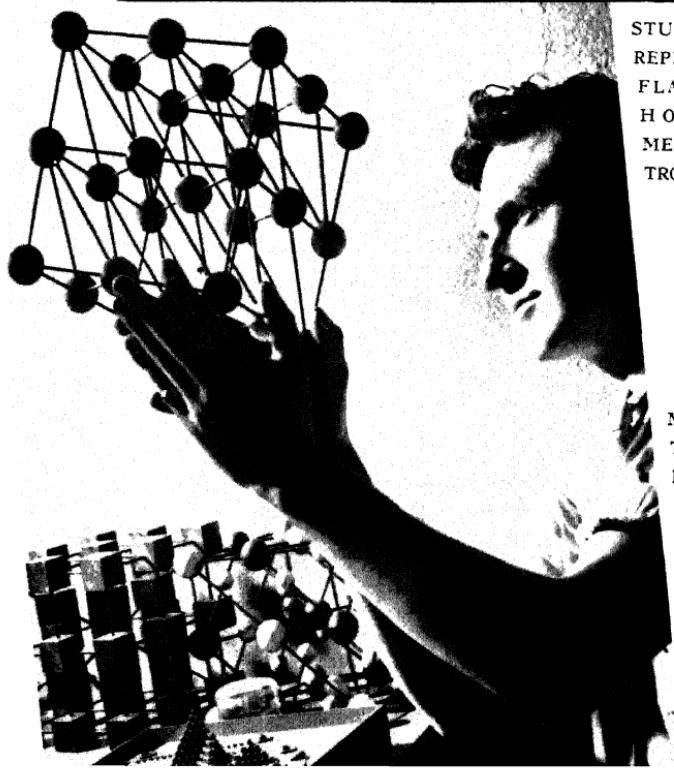
Several factors have been responsible for assigning the FM broadcasters to the short waves, about twenty feet in length, instead of to the thousand-foot waves of the AM stations. For one thing, this region was not so crowded; but it also has other advantages, for it is easier to design frequency-modulation circuits for these frequencies than for those in the usual broadcast band. And further, the waves being so small, it is simpler to provide antenna systems which are more efficient, or which have better directional characteristics—that is, in picking up signals from one preferred point of the compass—than with the longer waves.

An engineer, I. R. Weir, determined, both by calculations and actual tests, that the area of good broadcast reception with FM is about 33 times greater than with amplitude modulation. He has compared two AM transmitters fifteen miles apart on level ground with two FM units similarly separated. If the two AM stations operate simultaneously on one kilowatt of power, reception is satisfactory in a circle of a mile-and-a-half radius from each. Outside these circles, the stations interfere with each other. But now consider the action of the FM stations under the same conditions. Then the area around each in which the reception is satisfactory, with no interference from the other, is 33 times as great as with amplitude modulation.

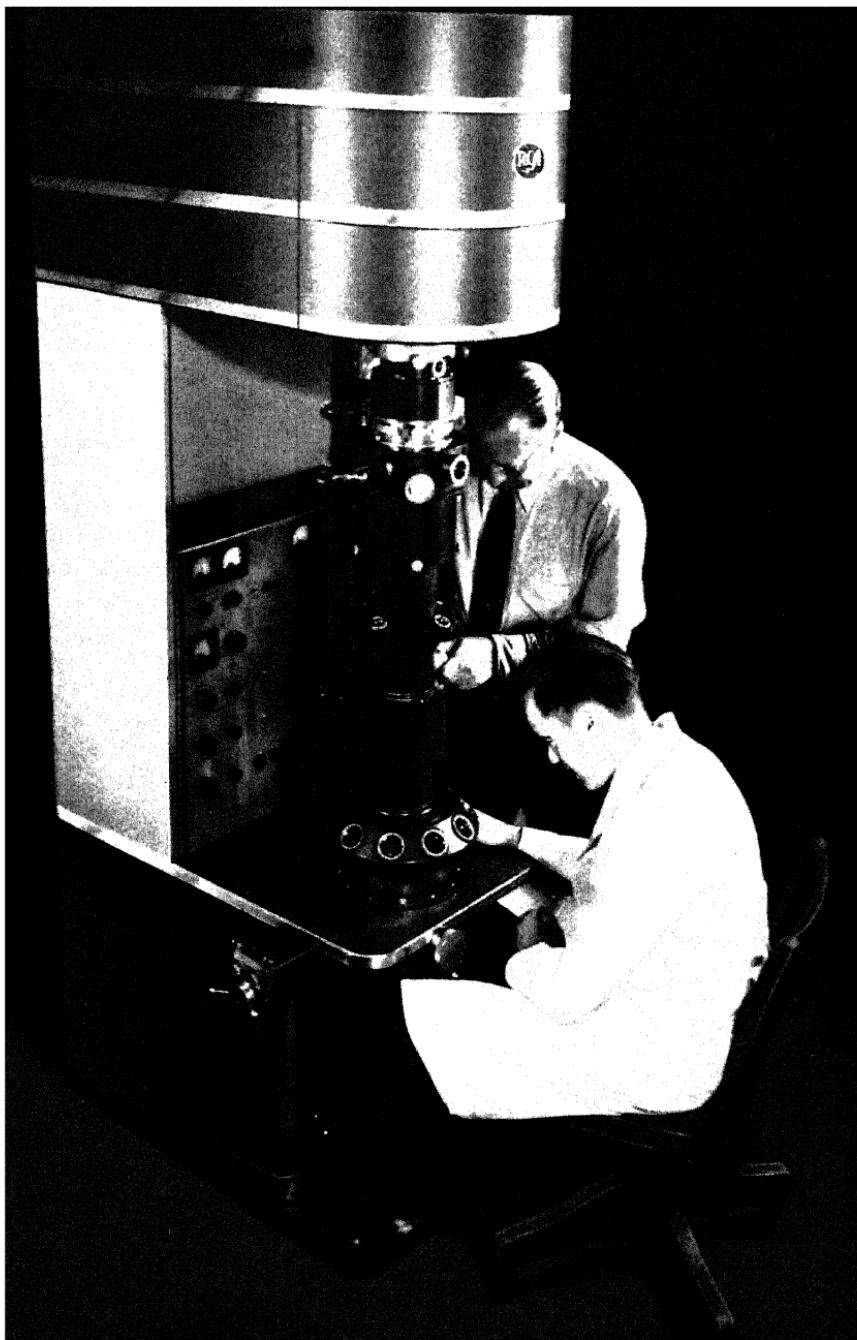
Weir determined what happened with increased power. Raising one of the AM stations to ten kilowatts increased its area of clear reception three-fold, and reduced that of the one-kilowatt station to a third of what it had been. With FM, the increase around the more powerful station was also about three, and the decrease around the weaker station was to a quarter; but this still left it with an area 23 times as great as that of one of the AM stations, even with equal powers. With FM there is practically no place where two stations are heard together. If you were to travel in an automobile, equipped with an FM receiver, from one transmitter to another, there would be a rather sudden change. Up to the point where they became nearly equal in intensity, one would be heard plainly, to the



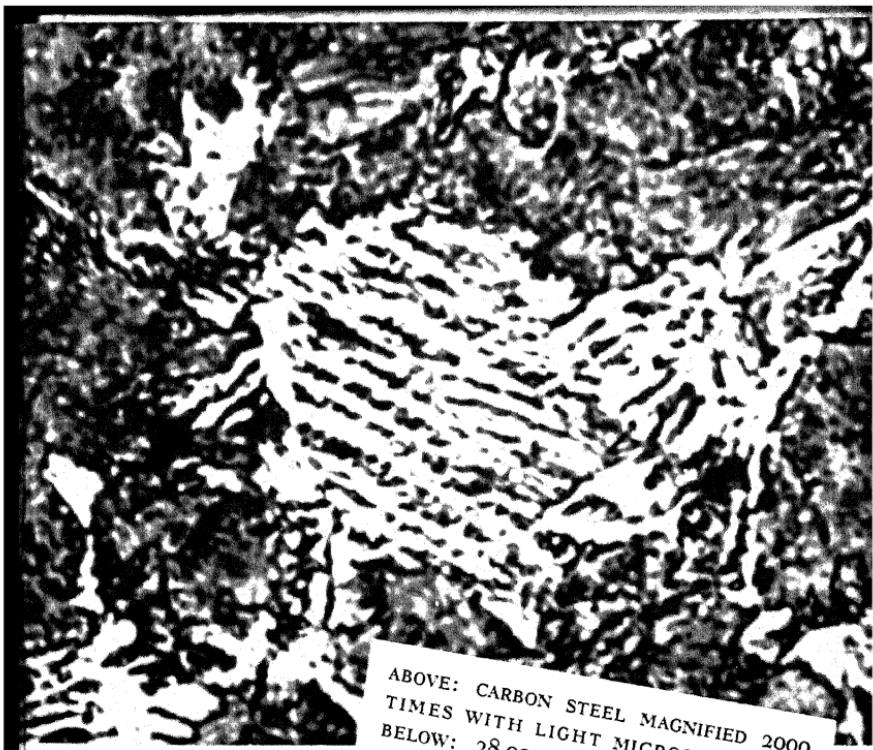
STUDYING PLASTIC
REPLICAS OF SNOW-
FLAKES SHOWED
HOW TO VIEW
METALS IN ELEC-
TRON MICROSCOPE
(see page 186)



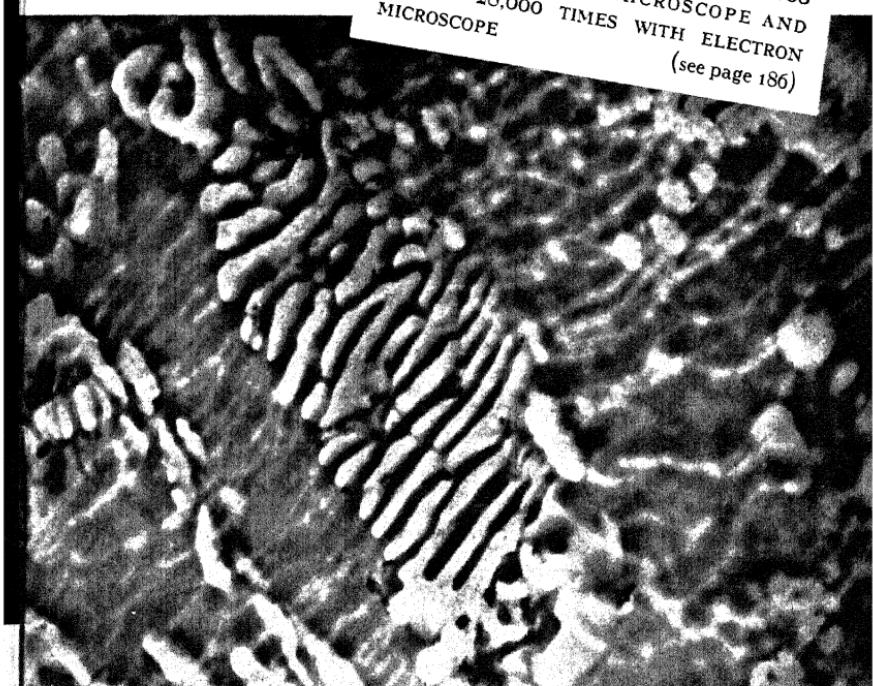
MODEL OF A CRY-
STAL AS REVEALED
BY THE ELEC-
TRON CAMERA
(see page 185)



THE ELECTRON MICROSCOPE EXTENDS MAN'S RANGE OF VISION
(see 1)



ABOVE: CARBON STEEL MAGNIFIED 2000
TIMES WITH LIGHT MICROSCOPE AND
MICROSCOPE
BELOW: 28,000 TIMES WITH ELECTRON
(see page 186)



HOW FM REDUCES STATIC TO THE VANISHING POINT

(see page 191)

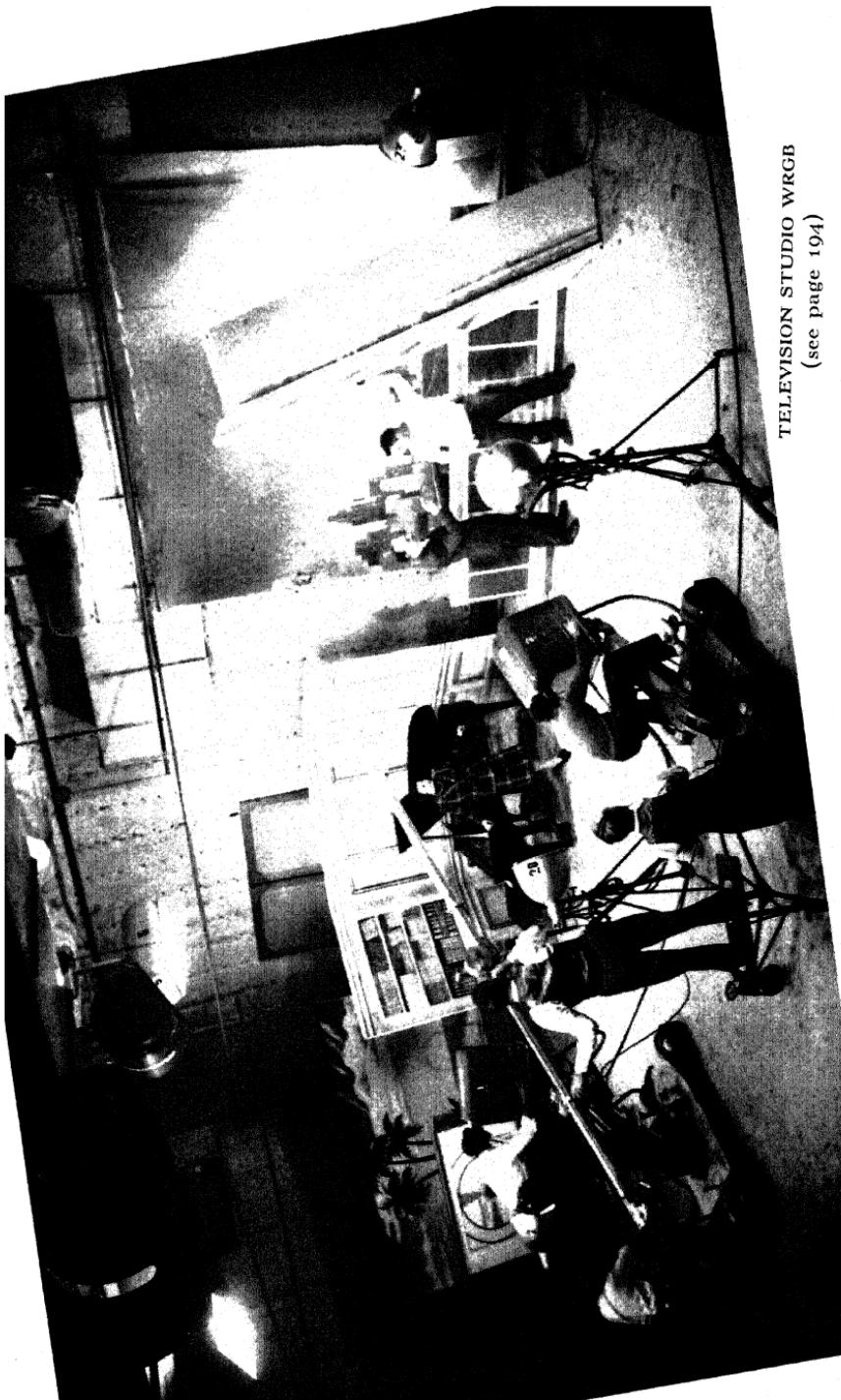
CONVENTIONAL RADIO

Sound	Carrier	Sound and Static on Carrier	What the Receiver Does	How Sound Looks at Loudspeaker

GENERAL ELECTRIC FM RADIO

Sound	Carrier	Sound and Static on Carrier	What the Receiver Does	How Sound Looks at Loudspeaker

TELEVISION STUDIO WRGB
(see page 194)

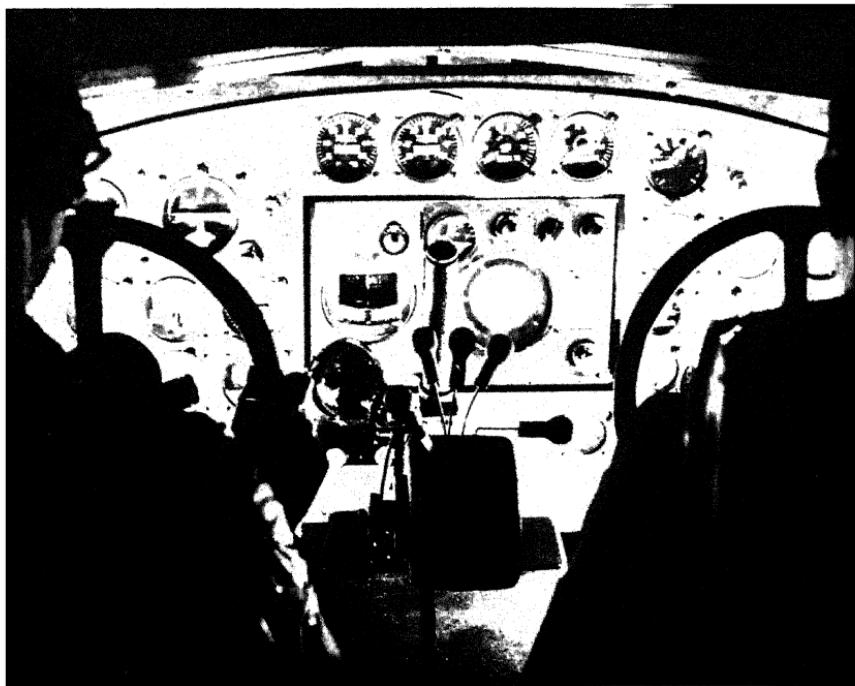




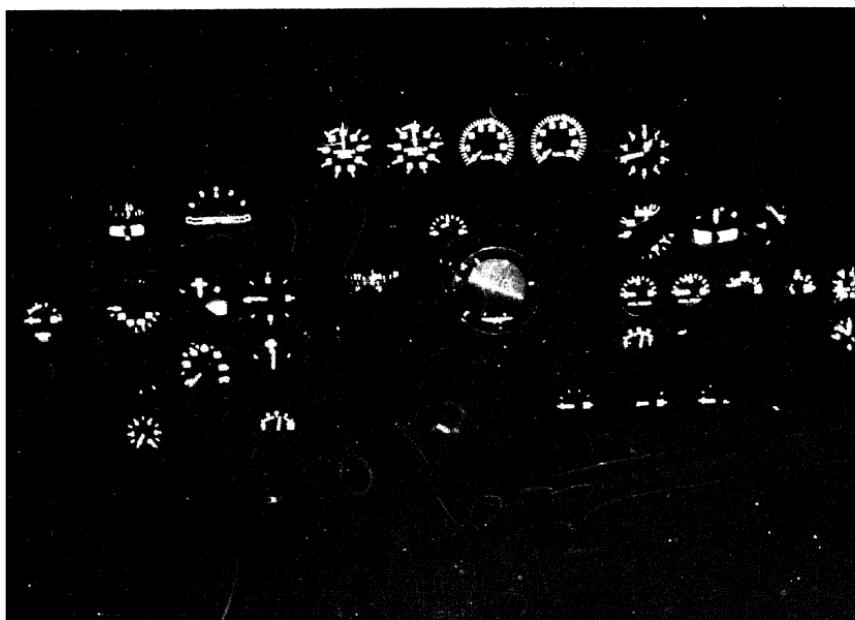
ICE MELTS IN A JAR OF WATER



HIGH-INTENSITY
TESTS FLAWS IN MERCURY LAMP
(see page 217)



FLUORESCENCE MAKES AIRPLANE INSTRUMENTS VISIBLE AT NIGHT
(see page 220)



exclusion of the other. Then soon afterwards you would enter the service area of the new station; that would be heard, and not the one you left behind. A similar experiment with AM would show a large area where both stations were heard together, for the next one would build up as the first one decreased.

There is another reason for the better quality of FM broadcasting, and that is the greater width of the roadway on which its signals are carried from transmitter to receiver. The deepest note which the ordinary human ear can detect vibrates about 16 times a second. This would be fourth C below middle C on the piano. No piano goes down that far, but large organ pipes do. At the other extreme are the highest pitched notes to which the ear is sensitive, which vibrate about 16,000 times a second. Typical of this is the squeak of a door, or the chirp of an insect. No ordinary musical instruments get this high; yet for every note of such an instrument there is not only the fundamental tone, but also a series of overtones, some of which approach this figure. These are made as the note is played, and are all higher pitched than the fundamental. With them, in a concert hall, the music sounds rich and natural; with the overtones eliminated, you still may recognize melodies, but the color of the music is gone.

With more than 880 radio stations in the United States crowded into the 105 separate and available channels of frequency which lie between 550 and 1600 kilocycles, it has been necessary to limit each channel to a ten-kilocycle width. Since the stations cannot go exactly to the edge of each channel and stop there, they actually keep within a range still narrower—not more than 5000 cycles across—and this makes it impossible to transmit, by conventional radio, the very deep and the very high notes; a great loss in the case of a symphony concert. With the 20-*kc* channels assigned to FM, the transmitter has an effective range of 15,000 cycles, which covers practically all the range of sounds from the deepest to the highest. The deepest notes of the oboe or of the contrabass, and the shrill tinkle of the

triangle or the high overtones of crashing cymbals, all reach the listener with frequency modulation.

Of course, at no point in the radio circuit must there be any limitation of the frequencies. Otherwise they are lost, and there is no advantage in having the transmitter able to broadcast them if they do not reach the FM-broadcasting station. Since the wire networks linking the nation's broadcasters were planned for AM and are mainly used with it, there was no point in making them able to carry a greater frequency range than the stations could broadcast. Consequently, an FM station that is connected to the source of a broadcast by the customary telephone program circuit never gets the full frequency range, though its transmission still retains the advantage of freedom from static. No doubt as FM broadcasting becomes more common, special program lines of high range will be provided for their use.

Frequency modulation's freedom from interference makes it of value in other radio fields. It is used for police radio communication, for carrying programs to schools, for public utilities to give instructions to service trucks, for communication between airplanes and the ground. United States quarantine tugs in Boston Harbor and the Quarantine Administrative Headquarters in the Boston Customs House can thus keep in touch, despite interference from static caused by compressors and other machinery in near-by plants that used to be a frequent source of interference.

But it will be its entertainment value, in the home, that is going to make FM radio familiar to most of us. We shall be able to hear speakers, orchestras, singers, outdoor events, with greater realism than at present. Frequency-modulation radio will go along with television; in fact, the FCC has ordered that all sound accompanying television transmission be sent by this method.

And what of television itself? It made its debut in the late 1920s. After pioneer work by Dr. E. F. W. Alexanderson of

the General Electric Company, and by a Washington inventor, C. Francis Jenkins, who was able to send moving silhouettes by radio, the first large-scale demonstration came in April, 1927. Mr. Herbert Hoover, then President Coolidge's Secretary of Commerce, was the most eminent person of a little group, of which the writer was a member, which gathered one afternoon in a transformed funeral parlor. It was no death, but a birth, that we witnessed—the birth of television. Different members of the party sat in front of the transmitter; a spot of light flashed over our faces many times a second. Each time the spot would fall on a light-colored area, illumination would be reflected to a bank of photocells, and the varying current from these would record the lights and shades of the subject. Amplified, carried over long-distance telephone lines to the Bell Telephone Laboratories in New York City, these currents controlled the light of a luminous plate in a neon tube. Revolving in front of the plate was a "scanning disc," with a series of holes around the edge which, at each instant, exposed a part of the viewing plate that corresponded to the position of the light spot at the same time on the subject in Washington. The viewers saw a recognizable portrait, in the pink color of glowing neon, of the subject two hundred miles away, for, since the plate was completely swept over many times per second, the same persistence of vision that makes motion pictures possible fused all the spots into a complete picture, just as the dots of a half-tone reproduction of a photograph are fused together.

About the same time, John L. Baird was making his early experiments in England, with results that were even cruder. He did not then use the moving spot, but flooded his subject with light and picked up parts of the image as formed by a lens. This required uncomfortably great quantities of light, so he often used invisible ultraviolet rays and as the picture became visible he had "noctovision," or vision at night.

The idea of television, curiously enough, dates back to 1884, for it was in that year that a German inventor named Nipkow was granted a patent on apparatus which, in its essentials, was

practically the same as its first successful modern counterpart, a selenium cell, made of an element which changes its electrical conductivity with the amount of light falling upon it, was the retina of his electric eye, and a very unsatisfactory one, not nearly so good as the modern photocell. Further, Nipkow lacked electronic tubes for amplification, so it is not surprising that his method never operated. In 1910 another inventor, A. Ekström, was granted a Swedish patent for a system like that of the Bell Laboratories, in which the spot of light, rather than the image, was moved. He too lacked the modern methods of amplification, and there is no record of his having succeeded. However, these preliminary ideas in no way detract from the credit due to the modern experimenters, who have achieved the old dream of "seeing at a distance."

In 1927, Dr. Alexanderson and his associates also achieved television, and in 1929 they reproduced their images on the fluorescent screen of a cathode-ray tube by a stream of electrons. This was the forerunner of modern electronic picture tubes. A little later Dr. V. K. Zworykin, Russian-born television expert of the Radio Corporation of America, developed an all-electronic television system, and this made the scanning disc obsolete, both for transmitting and receiving.

The eye of modern television is the camera which, like a photographic camera, has a lens to form an image on a plate. But the plate in this instance is a sheet of metal, in an evacuated glass tube, covered with myriads of tiny photoelectric cells. Each cell, as it receives light from the image formed upon the plate, builds up an electrical charge in proportion to the intensity of light falling on it. Thus, over a bright part of the picture, the minute cells accumulate relatively large charges, while those in the dark areas have practically none.

In a neck extending from the camera tube is an electron gun, which shoots a very thin beam of electrons toward the photo-cell mosaic. Outside the neck are coils of wire through which pass alternating currents, and these cause the electron beam to sweep over the plate at a speed of about three miles per second.

From the lower right it moves horizontally across; then starts over again just above the place where it started first, and makes another trip. After 525 such horizontal paths have been traced—in a thirtieth of a second—the whole area has been covered, and the beam goes back to the lower right to begin over again.

Every time one of the photocell elements is touched by the electron beam it releases its charge which, becoming an electrical current, is sent over cables to the amplifier and the transmitter. The intensity of this current at any instant is a measure of the amount of light falling on the part of the camera-tube plate which is then being scanned by the electrons. Next, this current is either sent over wire lines to the receiver or, in the case of radio television, modulates the carrier of the transmitter, usually by amplitude—though this could also be done by frequency.

Since each television picture is made up of about 275,000 separate units, corresponding to the dots of a half-tone reproduction, and since thirty of these are formed every second, it means that more than 8,000,000 individual impulses should be sent in a second to realize all the theoretical possibilities. This would mean a band far wider than required for the best FM sound transmission. In the whole broadcast range (from 600 to 1500 kc) which covers only 900,000 cycles, there is not enough room for one television station of such channel width.¹

When the signal reaches the television receiver, and the sight, or "video," component is sorted out from the sound or "audio" part, the electrical impulses are amplified and sent into the picture tube. In this a beam of electrons scans the viewing end in exact step with the electron beam in the camera tube, and falls on an inner coating of a fluorescent material, which glows where the electrons strike. The brilliance of the glow

¹ Actually, television channels assigned by the FCC are in the ultra-high frequency bands, where there is considerably more room, and the channels cover only 6,000,000 cycles (or six megacycles). Of this, part has to be used for the sound accompaniment, and some room has to be left between sound and sight, which leaves but 4.5 megacycles for the visual broadcast. For station WRGB, in Schenectady, for example, the center of the channel is 67.25 mc, or 4.6 meters.

varies with the intensity of the electron beam which, in turn, changes with the strength of the incoming signal. As this is controlled by the brightness of the corresponding point on the camera tube at the same instant, the picture is made up of light and dark areas which correspond to the original scene. Persistence of vision, just as it did with the old Nipkow scanning method, combines all the points into a continuous picture. To aid this, the glowing material that the electrons activate is often made slightly phosphorescent as well as fluorescent. That is, it continues to glow even after the exciting rays are removed. If this glow continues too long, however, moving objects appear with cometlike tails following them; but when the phosphorescence is limited to a thirtieth of a second, it merely bridges the interval and is gone by the next time the scanning electron beam comes along.

Early television experimenters found synchronization a problem; that is, the transmitting and receiving scanning discs had to move in exact correspondence. But with the electronic system, this is achieved by a separate electrical impulse, which periodically co-ordinates the electron beam in the camera with that in the picture tube. At the end of each line, and at the end of each separate picture, the beams are brought back to the starting point together, ready for another trip.

In the 1927 television days, one experimenter said to the author: "If we can tell a face from a fish, we think we're doing pretty well!"

Modern television, which is now being broadcast and received by a small number of sets from a handful of transmitters in a few cities, is a vast improvement, and is approximately equal in quality to good home movies. In 1941 the U. S. Government finally authorized commercial operation of television stations, but the advent of the war, and the cessation of the building of civilian radio receivers, halted the development which otherwise would then have come. However, experimentation did not entirely cease; some continued with war applications as the goal, so that after the peace television should be

ready for a rapid enlargement, which will undoubtedly far surpass that of sound broadcasting in the post-World War I days.

The ordinary television receiver displays its picture on a screen about as large as a double-page spread of this book. This size is satisfactory for a small group in the home, but would not do for an audience in a hall. At the time of the 1927 Bell demonstration from Washington to New York, a large viewing device was used, consisting of forty-eight parallel and interconnected glass tubes, filled with neon, inside which were a series of electrodes. In place of the scanning disc was a commutator—a motor-driven switch—which successively connected all these electrodes; and glowing spots of proper intensity appeared around each, thus making a large picture.

A little later Dr. Alexanderson showed large-screen television in another way. A neon "crater" lamp was used. This gives a small bright spot of light from glowing neon gas; and it was made to vary by the incoming signal. A scanning disc, with a spiral row of lenses instead of mere holes, focused this spot on a screen and made a series of lines of light across it, which formed the picture. Still another scheme, to get more light, replaced the neon lamp with an arc light; and to regulate the illumination this used a "Kerr cell," which is a sort of valve that permits a varying electric current to control the intensity of light shining through it. Again the lens disc was spun to produce the screen picture.

In line with the all-electronic tendency of modern television, the lens disc has gone the same road as the scanning disc. By using a picture tube of high intensity, the picture may be made brilliant enough to project in the same way as the illuminated slide of a stereopticon—by putting a lens in front of it and forming an enlarged image of the picture on a screen. By operating the picture tube at a very high voltage the picture can be made quite brilliant; but for a full-sized motion-picture theater screen, the same amount of light has to be considerably diluted as it is spread over the larger

waste of light in the projector must be reduced to a minimum, and the very "fastest" lenses must be employed.

Here is exactly the same problem involved in taking photographs in a dim light. Not only must the film be extremely sensitive, but the lens must have a large "focal ratio," which is the number of times the diameter of the lens goes into its distance from the film—or, in the television projector, its distance from the picture tube. Lenses in which this ratio has a value of F 2 or even F 1.5 have been used, their effective speed being further increased by the non-reflecting coatings already described. But in the most recent demonstration, which was given by the National Broadcasting Company in a New York theater, a new tool of the astronomer was employed.

In taking photographs of faint stars, the astronomer also requires great speed, combined with an instrument that will cover a relatively large area of the sky. About 1930 a young German astronomer of Hamburg, Bernard Schmidt, invented a type of camera which is now very popular and which bears his name. The ordinary telescope has a convex lens which forms the image, like a camera, and this is called a refractor. Other types of telescope, called reflectors, are also widely used, with a concave mirror to focus the light rays. The curve of such a mirror is not an arc of a circle, as that would not focus all the rays together, but is a parabola. The Schmidt camera, however, does make use of a spherical mirror, in which lines across the surface are circular arcs. To focus all the rays in the same place, they pass through a correcting plate before they strike the mirror. This is a complicated lens which is partly concave and partly convex. After the light rays pass through it, they hit the mirror in such a way that all are focused sharply on the curved film, about halfway between the plate and the mirror, which it faces.

It is a fundamental rule of optics that a beam of light does not care which way it goes; if the beam will pass through a lens system in one direction, it will go equally well if its route is reversed. So, with the Schmidt camera, the curved film can be

replaced with a curved source of light, the rays will be reflected from the spherical mirror, then will pass through the correcting plate; and they can be focused to form a large image on a screen. This is what the RCA television projector does. The curved surface of the picture tube takes the place of the film and, since the Schmidt camera can be made with a speed of F 1, this utilizes more of the light than any other projector. At the New York demonstration, the projector was sixty feet away from the screen, yet the picture, fifteen feet high and twenty feet wide, was almost as bright as the ordinary motion picture. Perhaps, in the future, with such a device, theaters will regularly show programs of events happening in other parts of the world, at the same time that they are occurring.

Even greater realism would be obtained if the television images, whether in home or theater, were in natural color; and this, too, has been achieved. The Bell Laboratories scientists did it in 1929, about the same time that Baird was doing it in England. To reproduce all the colors of a scene, three separate pictures are required, each showing one of the fundamental colors, red, green and blue. Color prints in books and magazines are made by superimposing three separate color impressions. In the 1929 television methods, three complete transmission systems were used. Properly colored filters picked out the colors desired. One system transmitted the reds, another the greens and the third the blues of the original. At the receiver, each picture was reproduced in the corresponding colors. With an arrangement of mirrors which partly reflected and partly transmitted light from the other side, the three were recombined, and the looker saw them fused into one picture again.

More recent experiments by Dr. Alexanderson in Schenectady, and by Dr. Peter C. Goldmark, chief television engineer of the Columbia Broadcasting System, make use fundamentally of the principles of the first commercially successful color-movie system. This was the "Kinemacolor" process which, in 1910, revealed to the world the glorious colors of the pageantry at the coronation of King George V, and also, the following year,

those of the Indian Durbar at Delhi, when he was crowned Emperor.

The Kinemacolor camera ran the film at a speed of thirty-two frames per second, twice that of the current standard for black and white. (Twenty-four frames per second became standard with the coming of sound films.) A revolving color filter, half red, half green, took alternate exposures in each color. In the projector revolved a similar disc, giving each frame the same color as it was taken with. Once more persistence of vision operated and the eye saw the pictures combined.

With two instead of three colors, it was not possible to reproduce all the tints of the original. Also, there was often trouble with "color fringes." That is, if a subject moved an arm, it would be in one place as the green frame was taken, but would have moved to a different position for the red. On the screen, instead of a sharply defined arm, would appear a blur of separate red and green images.

Both of these difficulties are eliminated in the new color-television method. The revolving screen has three colors, instead of two. And to eliminate fringes, Dr. Goldmark revolves his filter 250 per cent faster than it did in the Kinemacolor camera. With that system a complete picture, with both colors, took $\frac{1}{16}$ second. In the Goldmark camera the three components are all completed in $\frac{1}{40}$ second, so there is less chance for the color blurs to appear.

This method really involves no fundamental change from ordinary television, since all three colors are sent over a single channel. Essentially, any modern television system can be converted to color merely by putting color discs over the cameras and the receivers, and providing the means for moving them in step. This is not difficult, since exact synchronization must be provided in any event for the beam of electrons in the picture tube. And a receiver that is not equipped for color can still show the colored transmission—as black and white. Perhaps it is not too much to hope that, by the time television does achieve widespread popularity, it will all be in color.

The widespread popularity of sound broadcasting came with the development of the networks, enabling the great expense of producing an elaborate program to be spread over many stations. With sponsored programs the advertiser is assured of an audience sufficiently large to warrant his heavy costs. Television is even more expensive than sound, so it seems certain that some sort of television network will be essential if it is to develop.

Just as the ordinary ten-kilocycle channel for sound broadcasting will not transmit nearly enough range for television, neither will the telephone lines connecting broadcasting stations transmit the millions of separate impulses needed each second. Special equalizers and amplifiers do make it possible for good telephone circuits to carry about 3,000,000 cycles per second, and for television this may serve over short distances temporarily. But for city-to-city connections it has to be better than this; and the coaxial cable is one answer.

Long-distance telephony is usually carried from city to city by what might be thought of as radio over wires. That is, the voice currents, which are vibrating a few thousand times a second, and in the range to which the ear is sensitive, are stepped up to vibrate at frequencies similar to those used in radio transmission. The original vibrations, from zero to 4000 cycles per second, may be changed into a range from 60,000 to 64,000 cycles per second. Another conversation, going on at the same time, may be stepped up to the 64,000-68,000 range, another to 68,000-72,000. Long-distance trunk lines are capable of a range of 48,000 cycles, or from 60,000 to 108,000, so twelve separate conversations, each in its 4000 cycle band, can all be sent at the same time. Along the way amplifiers, or repeaters, give these currents occasional boosts. Thus, not a great deal of power is needed at the start, since power is added when needed along the line.

At the end are separate receivers for each conversation, and each is tuned to a particular 4000-cycle band, so they are sorted

out again. Then they are stepped down to vibrate at the rate to which the ear responds, and the other party hears the voice from afar faithfully reproduced, in spite of all that has been done to it en route.

Under present conditions a range of 48,000 cycles, carrying twelve conversations, represents about the limit that can be transmitted over the ordinary wires. To carry more it is necessary to go to still higher frequencies than 108,000, and then interference increases. For instance, there is more crosstalk; that is, one line picks up messages from a near-by line and mixes them in.

To overcome these difficulties, the Bell engineers turned to a type of conductor that had been studied years before and even used for some purposes, though their application was new. As first installed in 1935 between New York and Philadelphia this "coaxial cable," as it is called, consists of a copper tube about as big as a lead pencil. Running through its center, held in place by a disc insulator every few inches, is a copper wire. The wire and the tube form the two parts of the circuit, and the air between them is a much better insulator than any ordinary insulating material that might be used. At the same time, the copper tube acts as a shield to bar outside interference.

Actually, on account of the "skin effect," although the tube has a solid copper wall, the undesired interfering currents travel along the outer surface, to the ground, while the voice currents are concentrated on its inner surface. The higher the frequency, the more pronounced is this effect.

Thus, the coaxial cable can carry a range of a million cycles, or 240 messages simultaneously, each with its 4000-cycle band, and with a little space in between for clearance. Or, instead, the whole million cycles may be used for television. This was done in June, 1940, when the first intercity television broadcast was made. Scenes from the Republican National Convention in Philadelphia were sent out from the Empire State Building transmitter. It is for telephony, however, that the coaxial cable has been most used up to now. So successful did it prove that

in 1940 another was installed, between Minneapolis and Stevens Point, Wis. Actually such a cable is double; in a single larger housing there are two coaxial conductors, one for each direction.

Coaxial cables are expensive—\$20,000,000 has been estimated to be the cost of one crossing the continent. It hardly seems likely, therefore, that our present elaborate network of program lines for broadcasting will be duplicated for television. What is more probable is that we shall have radio links, used, perhaps, as branches from a few coaxial trunk lines.

The first radio link was put into service on January 12, 1940, when NBC television programs were first received from New York City, 129 miles away, by a special relay station in the Helderberg Mountains near Albany. These are passed on a mile and a half, again by radio, to the General Electric television station WRGB, situated on a cliff overlooking the three cities of Albany, Troy and Schenectady. In all of these the programs can be received clearly, though the original transmission from the New York station on the Empire State Building cannot ordinarily be observed.² The reason for this is that the short waves used for television travel in straight lines; they are not reflected back to the ground, as are the long broadcast waves, by the strata in the high atmosphere making up the Kennelly-Heaviside layer. Thus they are stopped by the intervening curve of the earth, since they do not jump around it.

The Radio Corporation of America makes use of radio transmission to carry television from points on Long Island to the New York City transmitter. In one demonstration, for example, views from Camp Upton, sixty-eight miles away, were relayed in three jumps. The NBC mobile transmitter, in two large trucks, sent the signals seventeen miles from the camp to Hauppauge, where they were automatically received and passed to Bellmore. This station sent them twenty-eight miles more to a receiver on the sixty-second floor of the RCA Building in New

² A radio link is also used to relay the programs from the WRGB studio in Schenectady to the same transmitter.

York City, whence wire lines carried them to the transmitter.

This was done with very low power—only five watts—in the intermediate relay transmitters, a feat possible largely because of the highly directional horn antennas used in the receivers. These point directly to the transmitter, and taper from their 4×6 foot openings, along their eight-foot length, to an apex a foot and a half square, where a small dipole antenna is located.

Though it is in broadcasting that most of us have contact with the wonders of radio, there are many other uses that have perhaps greater importance. Radio today makes possible the great network of aerial transport, warning the pilots of adverse weather conditions, and permitting them to keep their ground stations informed of their progress. Applied to police use, it is making crime more and more difficult. Automatic transmitters, carried miles aloft by small balloons, report weather conditions high in the atmosphere, permit more accurate forecasts of future weather. And all the time the use of radio for which it first gained fame—in calling aid to a sinking ship—has continued, especially when hostile submarines patrol our coast.

For the purposes both of business and diplomacy men can talk to one another though separated by oceans. Before the beginning of the Second World War, engineers of the Bell System had very nearly achieved their aim of making it possible for any person in the world with a telephone to talk to any other person similarly equipped. Such conversations would not be of much value, however, if a business rival, or an enemy, could listen to secrets and use them to his own advantage, so numerous “scrambling” methods have been devised, making the signal received by an ordinary set like so much gibberish. Yet the authorized receiver can unscramble it and make the speech perfectly intelligible again. One of these methods is to change the places of high- and low-pitched sound, so that “telephone company,” for example, sounds like “playofine crinko-

nope." Other methods are even more complicated; and the particular combination used can be changed frequently, so that even an enemy who knew the system and had the necessary apparatus would still lack the essential key to interpretation.

Within a few years, perhaps, telephone conversations across the Atlantic will take place by cable as well as radio, and then such juggling of the messages to gain secrecy will be unnecessary. The ordinary telegraph cable, like those which have connected America and Europe since 1865, does not respond quickly enough to transmit the rapidly changing currents required by telephony. The reason for this is that the cable is really a large condenser, which "stores" electricity. Hence it is necessary to charge it before a signal appears at the other end, and this takes an appreciable time.

In 1924 Dr. Oliver E. Buckley, now director of the Bell Telephone Laboratories, devised a cable with a sheath containing a new alloy called "permalloy." Although this speeded up the cable five or six times, it was still too slow for telephony, at least over a distance as great as that across the Atlantic. Even before this, in 1921, a telephone cable 105 nautical miles in length had been laid between Key West and Havana.

Further experiments showed that the use of another alloy, called "perminvar," would make possible the construction of a long-distance telephone cable, capable of spanning the 1800 miles from Newfoundland to Ireland; and in 1929 such a cable was projected. Though regular transatlantic radio-telephony had then been inaugurated, it was unreliable, and the expenditure of \$15,000,000, which the cable would have cost, was considered warranted to assure a continual connection.

In his 1942 Kelvin Lecture given before the Institution of Electrical Engineers in London, Dr. Buckley explained that the business depression caused a temporary postponement of the project. Then, as the reliability of radio-telephony was greatly improved, it was decided that such a cable, carrying only a single conversation, was no longer justified. On the other hand, if a cable capable of carrying simultaneously a number of con-

versations were feasible, the economic case might be different.

Though it still presents many problems, it now seems likely that such a cable can be made, and in his lecture Dr. Buckley outlined its features. As in land lines, such a cable would have to have repeater stations at regular intervals to give an extra push to the ever-weakening currents and send them on their way. But putting repeater stations on the bottom of the ocean is rather a different matter from placing them along a regularly patrolled land line. Since the lifting of a cable for repairs is a complex process, involving the grappling for it from a specially equipped ship, the parts of the cable repeater station must require little or no servicing. The Bell engineers set twenty years as the minimum time over which the station should work without attention.

Principally, Dr. Buckley pointed out, this is a matter of making a rugged and long-lived electronic tube. So a tube has been developed which already has given continual service for more than five years without deterioration. It seems likely that it will run for at least twenty years, but that remains to be proved. Such tubes are made for this special purpose, and they are hardly suitable for home radio sets! Long life is obtained only with the sacrifice of some other desirable qualities.

Using these tubes, the men at the Bell Laboratories have devised a repeater which is contained in a section of the cable itself. About two inches in diameter, and seven feet long, 47 of them, at 42-mile intervals, would be required in a cable connecting Newfoundland and Great Britain. The tubes need power for their operation, and it is planned to supply this over the cable itself from a direct-current supply.

The time has not yet come to build such a cable, and many important problems remain to be solved before it is really practicable. These solutions will come through the construction of trial sections, and their testing under a variety of conditions.

As foreseen by Dr. Buckley, however, there would be a pair of cables, one for east-west transmission, the other for west-east, since the repeater is a one-way device. In this manner, he

said, a band of 48,000 cycles could be transmitted. This would carry twelve simultaneous conversations with quality equal to the best present land telephone practice. If the quality be sacrificed slightly, though not enough to make the speech hard to understand, it would carry twice this many.

It is estimated that the cost of such a cable would be no higher than for short-wave radio systems to carry the same number of circuits. And there is also the better quality of cable-transmitted speech, its privacy and greater reliability which might even justify higher cost.

"When once the engineers are ready to give reasonable assurance of the cable," said Dr. Buckley, "I believe that it will not have to wait complete economic justification, because of the tremendous importance which it would have in insuring privacy and continuity of transatlantic telephone service." In fact, he added, "it is possible that once the cable were in service radio would be looked upon as a supplement to it."

XVI. *Light and Light Sources*

Man's earliest illumination was the sun; and it is perfectly correct to say that even in this age that celestial body, 92,900,000 miles away, is our only source of light. One form of energy is light; all energy comes ultimately from the sun; and much of man's ingenuity throughout past ages has been expended in bringing in the sun's brilliance, in keeping it to illuminate his dark hours. Of course, the cave men never realized that the wooden faggots they burned were actually giving off energy that the living tree had acquired from the solar radiation it had absorbed through its leaves.

It is fortunate that the eye has such adaptability that it can stand a range of brightness from the faintest visible light which can be seen to one that is actually uncomfortably brilliant: of about one to 1,000,000,000,000. Since we cannot control the brightness of the sun, artificial illumination, without such adaptability, would have to be many times brighter.

The most familiar unit of light intensity is the candlepower, which is approximately the brightness of an ordinary candle. But in technical work the lumen is more commonly used. This measures not the brightness but the quantity of light energy that flows out from a source. A lamp of one candlepower, from which it is given off uniformly in every direction, yields a little more than 12.5 lumens.

The eye is not equally sensitive to all colors. Light of yellow-green color affects it most; and to equal the apparent brightness of a particular yellow-green source five times as much power in orange-red light would be needed, or sixty times the power in blue-violet. What we call white light is simply the particular combination of the colors of the spectrum given off by sunlight, plus some light of a more bluish color which the sky scatters.

When, in an artificial light, we demand that the same proportions be observed, we are asking that it contain some of the colors we can see rather poorly.

If we have a lamp emitting only the yellow-green light that we see best, we can get the most light for our money. Such a lamp, if it were perfect, would yield 621 lumens for every watt of electricity put into it. As the yellow light of the sodium lamps used for highway illumination is approximately of this color, they are quite efficient compared to other sources—they give about 50–55 lumens per watt of power, or about a twelfth of what might be done. Since most of us do not find it pleasant to work or play under such a color, as we want things at night to have something like their normal hues, we ask for "white" or an approximation and this cuts the maximum theoretical efficiency of a lamp to about 225 lumens per watt. There is still considerable room for improvement, for the most efficient lamp yet developed to give white light (the high-intensity mercury lamp, with water cooling) yields only 65 lumens for every watt of power. However, our engineers need not feel too badly about this, since the sun, it has been estimated, gives only about one hundred lumens per watt.

The sun, like the incandescent lamps which give off light from a heated filament, radiates as well a considerable amount of the invisible ultraviolet and infrared rays, which are of no use directly for illumination. However, continual research has made the modern Mazda lamp a far more efficient device for converting electricity into light than was its prototype, Edison's first crude lamp that started to shine at Menlo Park on October 21, 1879. With a filament of carbon, these early lamps consumed somewhat less than 100 watts, and gave about 1.7 lumens per watt when they were new. But carbon evaporated from the filament and settled on the bulb, so that by the time they were about to burn out they would average scarcely better than one lumen per watt.

By 1900 the incandescent lamp was of age; Edison and others had worked to double its efficiency and make the average lamp

burn for six hundred hours. In that year Edison is reported to have remarked that it was then so perfected that he thought it unlikely that it would ever be materially improved.

Similar remarks have often been made. For example, it was only a few years after this, shortly before the Wright brothers made their first flight at Kitty Hawk, that a distinguished American scientist demonstrated, to his own satisfaction at least, that it was quite impossible for man ever to make a heavier-than-air machine which could get off the ground. Such a statement is very often the signal for someone to prove it wrong, and this was done in regard to Edison's pessimistic view.

It was in that same year, 1900, that the General Electric Research Laboratory was established. Since incandescent lighting has from the start been the backbone of the electrical industry, this was one of the problems that Dr. Willis R. Whitney, first director of the Laboratory, began to work upon. The result was the "Gem" lamp of 1905, produced by subjecting the specially treated filaments to high temperature before they were placed in the lamp, and thus giving them a "metallized" finish. This reduced the amount of blackening of the bulb in use, and these lamps, with the same efficiency as the old ones, burned nearly five times as long, or else, with the same life, were 25 per cent more efficient.

The next great improvement was to eliminate the carbon filament entirely. In 1906 lamps with a metal filament, made of tantalum, were introduced in the United States, but these were not satisfactory, as their life was short, especially with the alternating current then coming into wide use. A filament of tungsten was much better, and gave a result 80 per cent more efficient than the one in the Gem lamp.

Tungsten lamps, made in Europe, were brought into the United States, but they had to be handled like eggs. The filament, made by squirting a paste of tungsten powder and a binder through a small hole, then heating it, was extremely fragile. At the G-E Laboratory, Dr. William D. Coolidge improved this process, so that the filaments were considerably

stronger. Though these lamps still had to be handled with care, and would not stand up under the vibrations of a trolley car or a railroad train, it was decided to start their manufacture, and the necessary equipment was installed.

In the meantime Dr. Coolidge had solved the problem in another way. Most metallurgists had supposed that brittleness of tungsten was an inherent property that could not be overcome. But he found that it was unlike most metals, which, when once made ductile, become brittle as they are hammered, drawn through dies, and worked in other ways. By hammering and drawing hot tungsten, it proved possible to make it into a fine wire, of great strength and ductility. Because of the advantages of ductile tungsten, half a million dollars' worth of machinery for making squirmed filament lamps, together with a stock of unsold lamps of the same value, was scrapped, and the new lamp went into production in 1911.

Though these lamps would stand vibration, and were suitable for all kinds of service, they still showed a progressive blackening, and this was conquered by the work of another of the brilliant scientists whom Whitney had gathered round him—Dr. Irving Langmuir, whose scientific achievements were to win him the Nobel Prize in Chemistry in 1932.

It has been supposed that the blackening was connected with the slight amount of air that remained in the bulb, and that a better vacuum was the answer to the problem. But at that time a better vacuum could not be produced. So Dr. Langmuir turned to a research technique that has often proved effective. In an address to the American Chemical Society, he once said:

When it is suspected that some useful result is to be obtained by avoiding certain undesired factors, but it is found that these factors are very difficult to avoid, then it is a good plan to increase deliberately each of these factors in turn, so as to exaggerate their bad effects, and thus become so familiar with them that one can determine whether it is really worth while avoiding them.

For example, if you have in lamps a vacuum as good as you know how to produce, but suspect that the lamps would be better if you had a vacuum, say, one hundred times as good, it may be the best

policy, instead of attempting to devise methods of improving this vacuum, to spoil the vacuum deliberately in known ways. You may find that no improvement in vacuum is needed, or just how much better the vacuum needs to be.

Dr. Langmuir admitted that:

During these first few years, while I was having such a good time satisfying my curiosity and publishing scientific papers on chemical reactions at low pressures, I frequently wondered whether it was fair that I should spend my whole time in an industrial organization on such purely scientific work, for I confess I didn't see what applications could be made of it, nor did I even have any applications in mind. Several times I talked the matter over with Dr. Whitney, saying that I could not tell where this work was going to lead us. He replied that it was not necessary, as far as he was concerned, that it should lead anywhere. He would like to see me continue working along any fundamental lines that would give us more information in regard to the phenomena taking place in incandescent lamps.

Two years' work led to the conclusion that it was simply evaporation from the filament that made the bulbs blacken, and that improving the vacuum would not be of any help. Though this was a negative result, it was a profitable one, because it showed what was not the road to be followed, and saved wasting further time in that direction.

So taking gas out would not help; all right, then, how about putting gas in? Of course it would have to be an inert gas—one that did not react with the hot tungsten. Nitrogen would do; or better, one of the so-called "noble" gases, like argon, present in minute amounts in the atmosphere. He tried this, and found that even if the gas in the bulb were as dense as the atmosphere itself, there was a greatly decreased rate of evaporation of the metal. But the gas conducted heat away from the filament more rapidly than the vacuum, and this caused a loss of efficiency. Again came fundamental research, this time on the loss of heat from wires in a gas.

By making the filament large, it developed, there was not much more loss of heat, yet with more surface the larger filament gave more light. But a large filament conducts more elec-

tricity; consequently it could only be used in a high-power lamp. Then Langmuir found that a finer filament, with the higher resistance needed, could be coiled into a helix or "spiral." If the helix were tightly coiled, so long as they did not touch, the high resistance remained, yet so far as heat loss was concerned, it was the diameter of the coil, rather than of the wire, which counted. Today the wire is often coiled, and then again coiled, and gas-filled lamps are used in all but the smallest sizes.

From an efficiency in 1881 for Edison's lamps of 1.7 lumens for every watt of current used, and about 2.6 lumens per watt for his best lamps—at the time that he thought they could not be improved—this research has raised the figure more than 400 per cent. The modern 40-watt Mazda lamp with which, perhaps, you are reading these words, gives 11.6 lumens per watt when it is new, dropping only slightly to 10.6 lumens per watt when about 70 per cent of its life is gone. In higher wattages efficiency is even greater. A 1500-watt lamp, for instance, gives 22.2 lumens per watt when new. It has been estimated that our lighting bills are several million dollars less every day as a result of Langmuir's researches—and he doubted their practical value!

Incandescent lamps give their light from glowing solids. The light from a candle flame also comes from glowing solids, small particles of carbon, which deposit on a cold surface as soot when you hold it in the flame. The gas and oil flames are similar. So is the Welsbach burner with its mantle heated by a hot blue flame of gas—a device which greatly improved the efficiency of gas lighting, and enabled it to hold on for a time despite the increasing competition of electricity.

But an incandescent solid is not the only possible source of light—the sun, and the other stars, are all gaseous, and their light comes from a glowing gas, hot, to be sure. However, a gas can be excited to glow without necessarily heating it; you can bombard it with electrons, for example. These knock other

electrons out of their usual places in the gaseous atoms, and as they fall back light energy comes out.

About 1860 Heinrich Geissler, in Germany, sent electrical discharges of high voltages through glass tubes which contained minute amounts of air, or other gases. These Geissler tubes gave off light, but they were applied more for research, or for spectacular demonstrations, than for useful sources of illumination. But in 1904 an American, D. McFarlan Moore, introduced a light embodying similar principles. The first installation, in a Newark hardware store, consisted of a glass tube 1.75 inches in diameter and 180 feet long, going from one end of the store to the other and back. The tubes contained nitrogen, from the air, at low pressure, or carbon dioxide. The latter was not as efficient as nitrogen, but it gave a fine white light.

And about the same time Peter Cooper Hewitt, another American inventor, introduced the mercury-vapor arc lamp, in which a discharge through mercury vapor gave a brilliant and quite efficient blue-green light. Because its colors were those to which the photographic emulsions of that day were most sensitive, it was used widely in photographic studios. It also gives out large quantities of invisible ultraviolet rays, especially if the tube is of quartz, instead of glass which is partly opaque to them.

There are many substances called phosphors, which glow with visible light when struck by ultraviolet rays. This happens because the electrons in the phosphors that are knocked out of their usual orbits do not fall back in one step; otherwise the light they gave off would be just as invisible as that which they received. Instead, they may fall back in two, or even more, steps, and then may give off radiation which happens to be in the range to which the eye is sensitive. This is called fluorescence. In addition, some of these phosphors show phosphorescence by continuing to glow for a time, perhaps measured in hours, after the exciting light has been turned off. This results from a delay in the return of the electrons to their customary positions.

To remedy the lack of red light from the mercury-vapor lamp, its inventor had the ingenious idea of using fluorescence. He coated the reflector of the lamp with a phosphor called rhodamine. Excited not by ultraviolet but by visible green rays (which the lamp gives off copiously), rhodamine glows with a brilliant red. Thus, the lamp gave off the green light, the reflector filled in with red light, and the mixture was some approach to white. The main difficulty with the system, however, was that the rhodamine faded quickly.

The red light from neon gas, excited by an electrical discharge, has become very familiar, though not for illumination so much as for advertising signs. However, units have been made combining a mercury tube with a neon tube, and these give a very satisfactory light because the neon supplies the missing red.

However, mercury vapor itself may be made to give a white light if the pressure is great enough—many thousands of pounds to the square inch. Such lamps are quite small, the actual opening in the tube being not much bigger than a pin, though the wall of the tube is thick to withstand the pressure. It is usually made of quartz, which is less likely than glass to melt at the high temperature obtained. But even quartz will be melted in the most powerful of these high-pressure mercury lamps, and so the most potent are surrounded by jackets through which water flows to cool them.

Among lamps giving white light, these are the most efficient yet produced commercially, for they yield as many as 65 lumens per watt, which gets more than a quarter of the way to the 225 lumens per watt theoretically possible for a white light. They are not yet suitable for home lighting, though that may well be a forthcoming development. They are used for outdoor lighting, at airports, for example, or in motion picture studios.

Dr. N. T. Gordon, a G-E scientist, has devised a novel application of them, as shown in the picture, for testing glass and other transparent materials for defects. The light is so nearly con-

centrated to a point that when a beam shines on a piece of glass the shadow on a screen a short distance in back of it shows clearly, by wavy dark areas, the irregular areas. Differences in temperatures in a liquid produce similar effects—the illustration shows an ice cube melting in water, the cold, heavy water from the ice flowing to the bottom. That is what happens in your highball, and shows why it gets weaker as you let it stand.

The most efficient lamp yet devised for general lighting purposes is one that goes back to the principles of fluorescence. These lights are rapidly becoming very popular; you see them in restaurants, in barbershops, in stores, as well as in many new homes—tubular lamps usually giving a cool, white light. In the tube are two filaments from which electrons are emitted. It contains small amounts of argon and mercury vapor. First the electrons make the argon glow, and this starts the mercury; so if the tube were of clear glass, all you would see would be the faint blue light of the glowing gas mixture.

In actual use, however, this blue light never escapes. It happens to be rich in ultraviolet rays, and these fall on the solid phosphors which line the tube. They in turn convert the invisible to visible light, and that is what comes from the tube for illumination purposes. Because the wavelength of the ultraviolet light from the mercury vapor in such a tube has just the value that produces the maximum fluorescence from the phosphors used, these lamps are highly efficient; and a 15-watt fluorescent lamp will give as much light as an incandescent lamp of from 40 to 60 watts, depending on color.

If the phosphor is basically zinc silicate, the resultant light is green, a color to which the eye is highly sensitive, and the efficiency then is about 70 lumens per watt. But, again, people want white light. Beryllium added to the zinc silicate makes its light more yellow and orange. Compounds of tungsten give light more blue, while a compound of cadmium and silicon makes red light. Thus fluorescent lamps are available for light

of various colors. By mixing these different phosphors in proper proportions, each can be made to contribute to the spectrum, and white light is the result. This, however, is at the expense of efficiency, but even then the yield is 52 lumens per watt. These figures apply to lamps 48 inches long, a size commonly used. Smaller ones are also sold, but they are not quite so efficient, though their performance is well in advance of incandescent lighting.

Another advantage of fluorescent light is that, when necessary, it can be kept at low intensity, and since the ultraviolet that excites it is invisible, the total amount of light is also very low. For instance, in a motion picture theater, you may want to have a sign giving, possibly, emergency instructions. If the sign is printed in the usual way, the whole card must be illuminated, and a great deal of light is reflected from the background. But the Continental Lithographic Corporation, in Cleveland, has introduced a line of fluorescent inks. A sign thus printed can be flooded with enough ultraviolet so that the letters shine with sufficient brightness to be read; but no other light is seen. Such a method is useful for blackouts, as has been demonstrated in England. Road signs, too, or even a guide line down the middle of a road, might be painted with phosphors. Then, by equipping automobiles with ultraviolet "headlights," they could get around in the dark.

By painting the walls of a factory with a phosphorescent material, they will be charged, so that in case of power failure there will be enough glow for a time to enable the workers to find their way about. Panic, from being plunged into sudden darkness, would be prevented. Dr. E. W. Beggs, of the Westinghouse Electric and Manufacturing Company, has said that such a painted wall might be made to glow for many hours, with the intensity of full moonlight, by setting off in the room a single photoflash bulb.

And if a room is so provided with a phosphorescent or a fluorescent paint, an obvious step would be to place in it several

ultraviolet lamps, their radiation directed to the walls. This would give a uniform glow from a very large source, entirely free from glare; yet its brightness could be sufficient to allow any kind of work or reading. By using a combination of various phosphors, as for the fluorescent lamps, white light, or any color, could be secured without difficulty.

Fluorescence has proved a great boon to the aviator, particularly the pilot of a bomber on a night flight, or of a fighter plane, out after an enemy bomber. In either case, the pilot's eyes must be adapted to the dark, so that he can see as much as possible. Yet he must be able to read his instruments. If these are illuminated by a general lighting, even a faint one, there is a good deal of light spilled over. But if the pointers and dials of the instruments are painted with phosphors, and if the panel is flooded with ultraviolet, these alone are faintly visible, yet not bright enough to destroy the flier's dark adaptation. Essentially, this method is similar to the radium painting often used for alarm clock or watch dials. There we see a phosphor mixed with a radioactive substance, which excites it to glow. For extensive installations, the separate excitation with "black" light is less expensive, and admits of more accurate control. The brightness of the ultraviolet lamp, for example, may be varied, and the brilliance of the instruments can be always kept at the lowest possible intensity. An airplane instrument board, as seen by normal light and by fluorescence, is contrasted in the illustration.

In order to provide the exciting rays, a lamp similar to a fluorescent lamp without its lining is used. Or instead, it may be an actual fluorescent lamp, for some phosphors themselves give off ultraviolet rays. That is, they may be excited by rays of wavelength 2600 (measured in Angstrom units, about $\frac{1}{2}54,000,000$ inch) and the rays given off may be longer, though still below the 4000 figure that is the wavelength of the deepest violet light the eye can detect. Then these rays fall on the instruments, and they give off visible, and useful,

light. It is never possible for fluorescent radiation to have a wavelength less than that of the light, either visible or invisible, that excites it. For that reason, though ultraviolet rays may be made visible by this effect, we cannot use it for seeing infrared, the rays beyond the other end of the spectrum—the heat waves that are too long to affect the eye. Consequently, as described on page 164, more indirect means are required to pick up and detect the heat radiation from, for example, the hot exhaust gases of an airplane at night.

Electric lamps giving off ultraviolet, rather than visible, rays have another increasingly important use. They are powerful killers not only of germs, but also of those still smaller disease-bearing agencies, the viruses, which float in the air and are responsible for many epidemics.

Man, and even animals before he appeared on this planet, made use, unknowingly, of ultraviolet rays for antiseptic purposes. These came then, as they do now, in the rays from the sun. They are responsible for the sunburn for which you lie on the beach in summertime. Vitamin D, the absence of which in the diet results in rickets, is formed by the action of ultraviolet rays on ergosterol and related compounds, which are present in the body and in certain foods. To supply this vitamin Dr. Harry Steenbock, of the University of Wisconsin, invented a process for "irradiating" foods by ultraviolet radiation. Though he was granted a patent on this important process, its benefits have not been to his personal advantage, for he assigned the rights to a research foundation at the University of Wisconsin, which has been the donor of funds for much other research of importance.

In such irradiation ultraviolet electric lamps are used, with a mercury discharge in a quartz tube; for glass cuts out the shorter waves, which have the most effect. However, for germi-

cidal purposes a type of mercury lamp in a tube of special glass is often used. One form of such light is the Westinghouse Sterilamp.

A century ago hospital operations frequently brought death instead of life to the patient, so great was the danger of infection. But in the middle of the nineteenth century Lord Lister applied Pasteur's germ theory of disease when he showed that the gangrene which followed an operation was caused by germs carried on the hands and instruments of the surgeon and his helpers. Lister used carbolic acid as a sterilizer, and sprayed the same antiseptic into the air in the vicinity of the incision. Such measures were of great efficacy; much of the danger of surgery was eliminated; but there still remained, however, some source of infection even after the most elaborate precautions were taken. Out of 1735 surgical cases a few years ago at one large hospital, 206 patients showed traces of infection and 19 died, despite what seemed the best possible treatment. Dr. Deryl Hart, professor of surgery at Duke University Medical School, showed that the cause was in organisms which floated through the air. By placing ultraviolet lamps above the operating table, the air was sterilized, and an infection rate of 11.9 per cent was lowered to less than a quarter of one per cent.

Tests made in Philadelphia schools by Dr. M. W. Wells and Dr. W. F. Wells during the winter of 1940-41 showed that ultraviolet lamps produced, apparently, a notable reduction in the number of cases of measles, despite an epidemic which was the worst in several years. Measles is caused not by a germ but a virus, one of those mysterious agencies that are too small to be seen with the ordinary microscope. Probably the common cold has a similar origin. Measles usually attacks the younger children, yet, in one school where ultraviolet lamps flooded the rooms of the primary grades, this was reversed. The school had more measles cases than in any of ten previous years, but this was owing to cases in the upper classes, which had far more than the younger children.

Dr. William F. Wells suggests that this would have great

possibilities for preventing epidemics among soldiers, quartered in close contact in barracks, recreation rooms and mess halls. The same method appears to be of value, too, in preventing colds and influenza.

Still another very efficient light, which you encounter with increasing frequency illuminating roads and bridges, is one which shines with a not unpleasant golden-yellow color. Here the light comes from sodium vapor, likewise made to glow by an electrical discharge. Practically all the light emitted is visible; such lamps give as much as sixty lumens per watt, while in the laboratory, by protecting the lamps very effectively from heat loss, five times this output has been attained.

The advantage of sodium was known a long time before it was used. However, ordinary glass is rapidly attacked and blackened by hot sodium atoms; and it was not until the Corning Glass Works found a sodium-resistant glass, which could be coated on the inside of a bulb made of a less expensive glass, that the way to its utilization was cleared.

The sodium lamp is about the size and shape of a rolling pin, without handles at the ends. It contains some neon gas and a small bit of sodium metal. When the current starts flowing the neon glows, and for about five minutes it shines with a red color. But when the heat of the neon glow has vaporized the sodium, its vapor starts to shine with characteristic yellow color. Since there are about 10,000 times as many sodium atoms as there are neon, the red glow is completely lost. The lamp gets quite hot, and to avoid losses through radiated heat the bulbs are surrounded by a transparent thermos bottle. In very cold places even this is not adequate, and for such circumstances a second, larger, thermos bottle, outside the first, is used.

Because of their color and their slow starting, these lamps may perhaps never be used for indoor lighting, but they have proved ideal for highways, and considerably cheaper to operate than incandescent lamps. Many installations have resulted in a significant reduction in accidents along their routes. Probably this follows from the fact that their color is one to which

the eye is highly sensitive, and vision becomes more acute than with white light.

There is a common idea that the light of the firefly is an ideal which science should strive to emulate. It is true that the firefly's light is almost entirely of a green color to which the human eye is very sensitive. No one, however, seems to have asked the firefly whether he sees this color best. As it gives off light of only this color, none of its energy is wasted as heat or ultraviolet rays which we cannot see.

But this does not mean that the light of the firefly is efficient, in the same sense that we have talked about the efficiency of incandescent lamps. We want as much light as possible for the energy, in the form of electricity, that we put into our lamps. It has been rather hard to calculate how much energy the firefly uses for each lumen that he emits, but he seems to be not quite as efficient as an incandescent lamp. In the case of one variety of luminous bacteria, Dr. E. Newton Harvey, of Princeton University, a leading authority in the field of animal light, found that it gave only about one lumen per watt, or an efficiency poorer even than the first incandescent lamp. Dr. Harvey's researches have shown that such light comes generally from the interactions of two compounds, luciferin and luciferase, the latter belonging to the class of enzymes.

Chemists have found the way to make such chemical light in a manner comparable to the firefly's process. They use a rather rare and expensive chemical known as "three-amino-phthalhydrazide," in an alkaline solution. When chemicals supplying oxygen are added there is a chemical change and a bluish green light is emitted. This is cold light; in fact, it works perfectly well if ice cubes are floating around in the solution.

Unless there is a continual supply of the chemicals, such light lasts only a few minutes; and it has been estimated to cost about 25 million times as much as Mazda lamp light. If one has

an electric-light bill of a dollar a month, a mere \$25,000,000 would be the cost of providing equal illumination by the firefly's method. So probably chemical light is not going to replace electric light—at least not in the immediate future!

XVII. *Pictures of the Future*

In the rush of world-shaking events in the year 1939, an important anniversary was, for the most part, neglected. This was the centenary of the birth of photography, for it was in 1839 that Daguerre in France, and Fox Talbot in England, announced their inventions. Yet the closing fifteen years of the first century of photography was perhaps the period in which it made its greatest advance, both technically and in popularity. Since 1939 that advance has continued, with the further stimulation of war. High-speed lenses then combined with films of a new range of sensitivity in making possible photographs under conditions that would have been hopeless in earlier days. New processes now permit the amateur to take color photographs in an ordinary camera, and to secure prints of these pictures. Mobile lighting units, for exposures as short as $\frac{1}{20,000}$ of a second, making clear pictures of rapidly moving objects, are coming to be an essential part of any well-equipped studio. In place of the flash powder of former times which filled a room with smoke when used, our modern photographer has the convenient flash bulbs. Some of them even emit their total radiation in invisible infrared "light" and, with the use of specially sensitized films, literally allow pictures to be taken in the dark.

Motion pictures, which are after all a direct outcome of photographic processes, have had a comparable advance. Most epoch-marking was the introduction of sound pictures, which succeeded after several earlier and still-born attempts. New color processes brought to the motion pictures far greater realism than ever before. And movies at last came into the home, first in black and white, later in color, which is now the more popular.

All photography depends basically on the action of light on

silver salts—chiefly silver bromide. Though exactly what happens is still not entirely understood, it seems that, when light acts on a small crystal of silver bromide contained in the sensitive emulsion, minute particles of silver inside the crystal are freed from their bond with the bromine. This was demonstrated by two French scientists who shot electrons and X-rays through exposed but undeveloped silver-bromide crystals. They found the beam to be bent as by metallic silver, which is different from the effect that the bromide has on the rays. At the Eastman Kodak Research Laboratory the crystals have been examined with the electron microscope. Crystals exposed to as much light as used in practical photography show many tiny particles, and those of silver which form the latent image have not been identified. But, with much longer exposures, particles of silver inside the crystals are readily seen, magnified 25,000 diameters.

When the exposed film is developed, more of the silver bromide is reduced to metal formed around the nuclei already present. In the places where no light struck, none of these silver particles are formed, no such nuclei are provided, and the white silver bromide in these portions remains un-reduced. After development, this unchanged silver bromide must be removed. That is done in the fixing bath, with a chemical called sodium thiosulfate. Anyone who has ever developed a film, or seen it done, is familiar with the process, and knows how during fixation the film clears up from its milky appearance, leaving the negative with light areas of the picture formed by black masses of silver grains.¹

When the silver particles of developed and fixed film are examined under the ordinary light microscope, they appear as masses of coke. But when two Kodak scientists, C. E. Hall and A. L. Schoen, first examined them with the electron micro-

¹ The paper on which the negative is printed has an emulsion which is similar to that of the film, though less sensitive to light. Bromide papers, used for enlarging, contain silver bromide, as their name implies. Those used for contact printing, still slower, are generally of silver chloride, or a mixture of chloride and bromide.

scope, they found tangled masses of threads and ribbons. It would appear that development causes the silver to build up on the nuclei in one direction at first, thus forming filaments which wind around inside the silver-bromide crystal.

The ordinary emulsion is sensitive only to the blue and violet colors in light, and to the ultraviolet rays. That is why it can be developed by the use of a red darkroom lamp. But a number of years ago a German chemist named Vogel found that mixing dyes with the emulsions in manufacture sensitized them to other bands of color. A blue dye appears blue because it absorbs yellow (and other colors). The emulsion to which it is added becomes sensitive to yellow light. To sensitize to green or blue-green, a red dye should be used; while a green dye should sensitize to red or bluish-red. In general, this principle is the basis of the preparation of color-sensitive plates.

With the limited number of dyes which, in Vogel's time met the requirements for permanence, the orthochromatic plate was produced. This extended the sensitivity range to include the yellow of the spectrum. In 1904 the introduction by a German manufacturer of dyes called "cyanines" made possible the panchromatic plate, which extended the sensitivity into the red. British researches between 1918-1928, into the chemistry of these dyes, laid the groundwork for still further increases in sensitivity range. No longer are photographers limited to taking photographs in a band of color including only about a third of the spectrum visible to the eye, as they were in 1875; now the spectrum available to the photographic process covers about four times the extent of wavelengths that the eye does. And since 1925 the range into the infrared has been increased many fold. Scientific photographers find these methods of particular value, especially since it is now possible to sensitize selectively to certain regions in the visible or invisible spectrum.

As a result of this ability to sensitize plates to any part of the visible spectrum, color photography became practicable. Optically, red, green and blue are fundamental; and by mixing lights of these colors, any other color of the spectrum may be

reproduced. As early as 1890 a pioneer in color photography, Frederic E. Ives of Philadelphia, had put on the market a successful process. He would take three separate pictures of the same subject, one with green light, one with blue and one with red. Because of the low sensitivity of emulsions of that period to red light, that exposure had to be very long; and since the photographs were made successively, the method was not adapted to photographing moving subjects.

From each of the three negatives, Ives would make a print on another plate—that is, a lantern slide. These were placed in a triple projecting lantern, with three separate sets of lenses, and thrown on a screen together, with the three images coinciding. Over the slide taken with red light was a piece of red glass; the green slide was shown in green light and the blue in blue light. Thus, on the screen, the combinations of these colors gave all the hues of the original subject. Another invention by Ives was arranged so that, instead of projecting the picture, a person could look into an apparatus and the three pictures would be combined. In addition, this showed the scene in stereoscopic relief with a realism that no other still photographic process has ever surpassed.

Such a process as that of Ives is called additive, because it starts out with darkness on the screen and adds the colors to it. But the most commonly used methods today are subtractive—that is, they start with white light and take colors away. But obviously, if you take away the same colors that you would supply in the additive process, the results are not the same.

Suppose we have three slides, such as those used in Ives' triple projector. It might seem that we could dye each with the same color used to project it, lay the three in a pile, and a single color picture would result. But this will not work. The dye would be uniform over each film, and when they are together would stop all light from passing through. However, there are

methods of forming dye images—processes in which the silver image, the opaque part of the picture, is replaced by dye, leaving clear and uncolored the areas originally transparent. If such dye images be formed, using red for the picture taken in red light, blue for the one made in blue light and green for that which shows the greens in the original, and if these are laid together, the picture will be in color. But—the colors will be complementary to those of the original. The blue sky will be orange, a red rose will appear bluish-green, and green leaves will be violet.

However, if the individual dye images be made in colors themselves complementary to those used for taking the respective negatives, the three can be combined to give a faithful reproduction of the scene. Take the red rose, for example, and to make it simpler, imagine that it is in a white vase, and photographed against a black background. On the red-sensitive slide, which has the bluish-green dye image, the rose itself is clear. Since it looked dark to the green image, this slide, printed in magenta, a mixture of red and blue, has color where the rose is shown. Likewise the blue slide, which is printed in yellow, shows the rose in that color. In all three the vase is clear, and in all three the background is in the color of the dye.

Now, when these films are laid one on top of another and examined against a white illumination, the white light goes through the vase image without interruption, and it appears white. The background stops all the rays and appears black. The rose appears in the light that penetrated the magenta and yellow, and consequently is red, because the yellow dye is not a pure spectral yellow but lets through some green and red as well. Only red can get through both magenta and yellow.

The case is similar with other colors. A green leaf, for instance, would appear in light that was able to pass through both the yellow and blue-green dyes, and only green can do this. If there is also a blue flower in the picture, this would be formed by light that had been transmitted both by the blue-green and magenta dyes.

There are simpler ways, however, of taking the three images than one after another in an ordinary camera. Professional color studios often use "single-shot" cameras. One of these has a single lens, but three plate or film holders, and two mirrors, each only partially silvered, which reflect about a third of the light and transmit the rest. These mirrors divide the light into three parts and feed it, through appropriate color filters, to the three plates or films. From these three negatives, transparencies or prints can be made by various methods, all of which use essentially the principles described above. Still simpler than the three-way camera is the "tripack," three unexposed films, of proper sensitivity, held tightly together and exposed at once. Since the light has to pass through the first film to get to the second, and through both the first and second to reach the third, the back one is apt to be blurred. But if the three are very thin, and in intimate contact, there is no chance for blurring. In the same way, you can lay a piece of waxed paper over printing and read it clearly, but if you hold it a short distance above, the printing is blurred.

This is what is done in the most popular of modern color processes—Kodachrome. Three photographic emulsions are placed on the same film and, to aid in the selective effect for the different colors, screening dyes are added to them. This process was invented by two scientists at the Kodak Laboratory, Leopold Godowsky, Jr., and Leopold D. Mannes, who devised a most ingenious scheme of developing. As originally introduced in 1935, the film was first developed, and in all three emulsion layers the latent image turned to silver. But, without fixing, these images were dissolved away with a special bleaching solution. Then the film was exposed to light, to make the remaining silver bromide developable. Next, this was developed, but in a peculiar kind of "coupling" developer, first applied by Rudolph Fischer in 1912. The effect is to form, along with the silver image and at the same time it is developed, a dye image as well.

After the original silver image had been bleached, and the film

had been re-exposed to light, it was treated with a coupling developer which formed a blue-green image in all three layers. Next the film was subjected to a bleach which was able to penetrate only the top two layers, where it converted these images back to silver bromide and destroyed the dye, though leaving the bottom layer unaffected. Then the film went to another coupler developer which deposited silver and a magenta image in each of the top two layers. But again it was bleached, this time with a chemical of such feeble penetration that only the top layer was affected, by having its dye destroyed and the silver converted back to the bromide. In the fourth and last development, a yellow image was formed in the top layer, together with one of silver. Then another bleach was applied, this time able to reach all layers, but not to affect the dyes. It did, however, convert all the silver images back into silver bromide. Then, finally, the film was fixed, all the silver bromide dissolved away, and only the three dye images, properly placed with respect to each other and combining to form a color picture, remained.

All this sounds pretty complicated—and so it is. One need not wonder that in putting Kodachrome on the market the Eastman Company returned to the policy they had used when the first Kodaks appeared half a century ago—"You press the button, we do the rest." But the accurate and efficient machines at Rochester did "the rest" and this process made popular color photography, in eight and 16 mm amateur movies, and in the 35 mm film for miniature cameras of the Leica and Contax type. Later, cut film was introduced for professional use, in sizes such as 8×10 inches, or even 11×14 inches.

By this time, however, the original process had been simplified to the one used today. The film is practically the same, and is developed first to convert all the exposed parts to silver. But then it is exposed, through the film base, to red light, which acts only on the unexposed part of the bottom layer. This is developed with a coupling developer that forms a blue-green positive image along with the additional silver image. Then

the top of the film is exposed to blue light, and goes to a developer with a coupler forming a yellow image. By this time the only undeveloped silver bromide remaining is that of the positive image in the middle layer. If a developer is made strong enough, it can convert even unexposed silver bromide to silver. Thus, the positive of the middle layer is developed with magenta-forming coupler. Next the three layers of silver are removed, and this leaves only the three dye images, all in the proper relation to each other.

Until 1941 such color pictures were generally available only as transparencies. That is, they had to be used as lantern slides projected on a screen, or viewed by holding against a brightly illuminated surface. Only by somewhat difficult and expensive methods could they be made into color prints on paper. But in the summer of 1941 the Eastman Company began production of enlarged color prints, both from the 35 mm film and from the larger cut sizes. Essentially, the material used for these prints is the triple Kodachrome emulsion on a backing of white, opaque film, which has proved more satisfactory than paper.

The original idea for a color process by coupler development involved incorporating right into each of the three emulsions the couplers which, in the process of development, would produce the desired dyes. At that time it was found very difficult to keep these couplers in their proper places, they tended to wander into other layers. However, after 1935 when Kodachrome was introduced, the Agfa company in Germany brought out Agfacolor, which successfully used Fischer's original method. In the meantime Eastman scientists had devised another method, by which, as Dr. C. E. K. Mees, Eastman research director, described it in a lecture before the Franklin Institute:

The couplers in their emulsion layers are not dissolved in the gelatin layer itself, but are carried in very small particles of organic materials which protect them from the gelatin and, at the same time, protect the silver bromide from any interaction with the couplers. When development takes place, the oxidation product of the developing agent

dissolves in the organic material and there reacts with the couplers, so that the dyes are formed in the small particles dispersed throughout the layers. This process might be known technically as the "protected coupler" process.²

Perfection of color-photographic processes has also had an important military application, for with them can be penetrated much of the camouflage that would hide enemy territory in black-and-white photographs. Experts of the U. S. Army Air Corps stationed at Wright Field have been able to take brilliant color photographs from about three miles altitude, and can probably double this figure. A three-lens camera, each with appropriate filter, takes the three photographs simultaneously.

Not always, however, is the resulting picture an accurate reproduction of what the flier saw from the plane at the time the exposure was made; nor is this at all desirable. By using infrared-sensitive film for black-and-white photographs, it is possible to see through the haze (but not fog), though this disturbs the color balance in color photography. Using a process of trial and error, Army men have laid out accurately colored 50-foot-long strips of felt on the ground and photographed them from various heights and under various atmospheric conditions. Thus they learn the particular combinations of films and filters that produce the best results under all circumstances.

Even at night, color as well as black-and-white aerial photographs can be taken. Brilliant-colored flash bombs are dropped that can be seen two hundred miles away. An electric eye on the plane, which is above and hidden in the glare, trips the

² In January, 1942, this process was placed on the market as Kodacolor, using again the name of the first successful amateur color-movie process, one which became obsolete with the perfection of Kodachrome. The films are now sold, in roll form, for all popular amateur-sized cameras, except those using 35 mm film. Developed by the company, the negatives not only are reversed in lights and shades, but also the colors are complementary, with yellow skies, and blue-green lips. But these can be printed on paper coated with a similar emulsion; then a second reversal of light and color values produces a correct reproduction of the original.

shutter of the camera when the flash is at its height. Again the films and filters have to be carefully chosen, to balance with the color of the flash.

Synchronized flashes have also become important in ordinary photography on the ground. The old flash powder, used a generation ago, consisted of powdered magnesium mixed with a chemical supplying oxygen to burn it. Using such powder the usual way, the camera would be set on a firm support, the shutter would be opened, the flash exploded, and the shutter closed. Devices for operating the shutter just as the flash went off were made, but did not work too well.

At the end of the 1920s, in Germany, the photoflash lamp was introduced—a glass bulb containing aluminum foil and filled with oxygen. An electrically operated fuse, which would work on the current from a battery or from the lighting circuit, set it off, and the burning aluminum gave a brilliant light—all inside the bulb, which confined the smoke. Soon afterwards these were made available in the United States, and immediately flash powder became obsolete. Accurate and reliable synchronizing devices were perfected, enabling short exposures to be taken under any lighting conditions. They proved a great boon to newspaper photographers, who often use them to supplement daylight under conditions where a powder flash would not have been considered feasible.

The ordinary foil-filled flash bulb starts to give out light about two-hundredths of a second after the current is applied to the bulb. About five-hundredths of a second later the flash is over. But the peak of illumination comes at about 0.035 seconds, and most of the light is emitted in a time considerably shorter than that of the whole flash. Smaller bulbs, which give less total light, operate more rapidly, while others have been made, containing aluminum wire instead of foil, in which the light is more evenly distributed over the entire period.

The shutter has to be synchronized to operate during the time the flash is at its height. Naturally, the light that the bulb gives out before the shutter opens and after it closes is not

utilized, and this limits the shortness of the exposure that can be given. For most work, however, this is not a serious limitation.

Working at the Massachusetts Institute of Technology, Dr. Harold E. Edgerton and his associates invented a far faster flash that operates electrically. This has been introduced commercially by the Eastman Company as the "Kodatron speed-lamp." Though Dr. Edgerton obtained shutter speeds as short as a hundred-thousandth of a second, this is not needed for ordinary work, and the Kodatron lamp gives a flash of $\frac{1}{7500}$ of a second. A portable battery-operated model, just introduced, works at $\frac{1}{20,000}$ of a second.

In such a lamp, electric current, raised to high voltage, charges a condenser in about ten seconds. Then this is very rapidly discharged through a tube containing the rare gases krypton and xenon, which glow with a light equal, in the case of the larger unit, to 50,000 forty-watt Mazda lamps. No shutter can operate in a time so short, and it does not need to; its speed needs only to be short enough to prevent any other light in the room from making an image. It opens, the flash goes off, and then it closes—the flash itself providing the timing.

Though the most spectacular results of such high-speed photography have been in stopping fast-moving athletes or dancers, or technical subjects like machinery in rapid motion, the lamp is proving useful for portraiture as well. When the first photographs of human beings were made, the subject had to sit still in bright sunlight for several minutes. In those days clamps were used to hold the victim's head stationary. As faster lenses and films were made, such instruments of torture were eliminated, but still exposures of as much as half a second were, and are, common in portrait studios, and usually today the subject has to "hold it." But with the Kodatron lamp, the subject may be moving as rapidly as he can, moving his hands, perhaps, in animated conversation. The lamp will stop him as the picture is made. This is particularly valuable for pictures of restless children and animals.

Not only have lights made high-speed photography possible, but, to utilize them, the films must be extremely sensitive; and in the past few years the manufacturers have found various means of making films which give good pictures with amounts of illumination that would have been unbelievably small twenty years ago. Then speed in a film was obtained only at the cost of graininess. That is, in the sensitive film or plate, the silver grains were relatively quite large, producing a difference in results comparable to that between the pictures in this book and those in a newspaper. But now fast films, yet with fine grain, can be obtained. Combined with development which preserves this fine grain, big enlargements from little negatives can be made; and this has partly accounted for the popularity of the miniature camera, which can be so easily handled.

Making pictures with short exposures in a room with ordinary lighting, and without the use of a flash, is also aided by the fast lenses with which modern cameras may be equipped. The speed of a lens, which determines the amount of light that gets through to the film, is measured, as already mentioned, by the F value—the ratio between the distance of the lens from the film when focused on far-away objects, and the lens' diameter. Twenty years ago an F 4.5 lens was the fastest generally available; now F 2 or even F 1.5 is not unusual. Since the speed is proportional (inversely) to the square of the F value, an F 2 lens admits about five times the amount of light of one that is F 4.

In astronomical photography the Schmidt camera ³ is now widely used. This gives a speed of even F. 1; and with it, Dr. Harlow Shapley, director of the Harvard College Observatory has predicted, will come the greatest contributions to astronomy during the next decade. The Schmidt camera is not very well adapted to ordinary photography, but its high speed has made it invaluable for aerial photographs. Though details of

³ Also referred to on page 200 in connection with its reverse use as a television projector.

this camera have not been revealed, it is known that a Schmidt aerial camera is now being made in quantity for the Army Air Service.

The use of fine-grain film also has made possible an answer to the problem which confronts every librarian of preserving an ever-increasing mass of material. A large book can be photographed, page by page, on a 35 or even 16 mm film. The grain is so fine that the film may be put into a special projector and viewed in the original size, or perhaps larger, with complete clarity. Banks use such a device, the Recordak, a product of the Eastman Company, to record every check they handle, thus providing, in small space, a permanent record of their transactions. In the U. S. draft lotteries the same device was used to record, in a form that could not be questioned, the order of drawing of the numbers.

This system, called micro-film, has also aided soldiers at distant stations to keep in touch with the folks back home. It was first used for the British troops in the Middle East. A description prepared by the Eastman Kodak Company explains its working as follows:

Tommy Atkins writes his letter on a special sheet measuring $8\frac{1}{2}$ inches by 11 inches and prints his address in block letters on a panel at the foot. The completed sheet is then photographed on a considerably reduced scale— $\frac{1}{2}$ of an inch by $\frac{5}{8}$ of an inch, to be precise—with a Recordak. The film is then dispatched by airplane, and upon arrival in England a 4-inch by 5-inch enlargement is made. It is then placed in a paneled envelope leaving only the address exposed.

Seventeen hundred letters can be photographed on a single 100-foot roll of micro-film, at the rate of 40 to 50 a minute. The film weighs only $\frac{1}{100}$ as much as the 1700 letters.

The miniature film images are enlarged on a roll of continuous photographic paper and processed at the rate of 1200 letters an hour. An automatic chopper, actuated by a photoelectric cell, separates the letters.

The great advantage of this method is the saving in weight. The first 50,000 Airgraph letters, which would have weighed over 1600 pounds if they had been written in the ordinary way,

used instead only 13 pounds of film. The next 85,000, instead of 1.5 tons, weighed only 20 pounds. This made it possible to send them all the way by air. Ordinary air mail from the Middle East, which costs more, has to be carried a considerable portion of the distance by sea, and takes as much as five weeks on the route, while the Airgraph letters are delivered in ten days or less. The same method was later applied for the benefit of U. S. troops in distant lands.

The motion-picture industry has shared greatly in the improvements in films and lenses that have so aided still photography, but the most significant change it has had in the past fifteen years has been the complete adoption of sound. It is hard to realize today that it was only as recently as August 21, 1926, that Warner Brothers released in New York their first feature sound picture *Don Juan*, with the sound on 16-inch phonograph discs. These were recorded and reproduced with electronic tubes, which made it possible to drive the record at the projector and to carry voice currents over wires to loud speakers in back of the screen—the point from which the sounds must emanate. Earlier processes of sound pictures, where the record had to be played close to the horn through which the sound was thrown, required complex synchronizing arrangements to keep record and film in step. But with the Vitaphone, the name given to Warner Brothers' method, the record was driven by the same motor that ran the projector, and both were controlled by the same operator.

Since then recording on the film itself has completely taken the place of the discs. The only use for the latter in sound movies is to make play-backs. That is, when a scene is taken, the sound is recorded not only on film but on a wax disc as well. This can be played back immediately to the cast and directors. If not satisfactory, the scene can be played over again while everything is ready.

There are several main steps involved in making a sound

film. The sound is picked up through a microphone, just as if it were going to be broadcast. Then it is amplified and operates some sort of light valve, which varies, in step with the current, the amount of light passing through; or else it controls the brightness of a special kind of lamp. In either event a changing light, modulated by the original sound, falls on the edge of a moving film. When developed, this shows either a band of light-and-dark strips or a white one of varying width. Though usually the sound record, except in news reels, is recorded separately from the film on which the scene is photographed, the sound track is printed alongside the picture in the positive to be projected. Thus there is no possibility of sound and picture getting out of step. In the projector there is a "sound head" through which the film runs after the picture has been thrown on the screen. A bright light is focused sharply on the sound track; on the opposite side is a photoelectric cell. The varying current from the cell is amplified, and operates the loud speaker.

With sound and color together, the motion pictures have acquired a new degree of realism. Technicolor is the color process most used in the theater. By means of a prism serving as a "beam-splitter," light from the lens is divided into two parts. One is reflected to the side and falls on one film, while the rest, which passes through the prism, reaches a bipack—two more films which run through the camera with emulsions in contact. Filters, and films of different color sensitivity, sort out the three fundamental colors, so that one film records each.

From each negative is made a positive film with an image in colorless gelatin which is able to absorb dye. Each film is dyed and then used, like a rubber stamp, to print or transfer the color to another film. By thus printing the three, one above another, the full-color picture is obtained. Actually the film on which these are applied has a faint silver image to aid in accurate registration of the colors. The sound track is printed in the usual way, and is also formed of silver.

For some motion-picture effects, it is desirable to show

sharply only actors and objects at about the same distance from the camera; but there are other cases where very close and very distant ones should all be focused equally well. Orson Welles, in *Citizen Kane*, made effective dramatic use of this method. But in using it optical difficulties are encountered. A lens of small F value (i. e., a fast one) has very little "depth of focus." Welles had to have his cameramen use their lenses at high F. values; and to overcome the loss of light, the illumination had to be very intense.

Recently two inventions have been made which allow such results without disturbing the lenses' speed. One was invented by Dr. A. N. Goldsmith, and can be used only with artificial light. The other, invented by Dr. L. M. Dieterich and improved in practice by D. Stanley Smith, is called the "Electroplane" camera, and works out of doors as well.

To change the focus from near to far objects, the distance between lens and film must be changed. The nearer an object is, the farther out the lens must extend. In the Goldsmith process the lens vibrates back and forth, making a complete travel for each picture. The illumination of the studio changes in step, so that when it is focused on the foreground, the foreground is lighted; as the lens moves in and the middle distance is in focus, that gets the light; and then the far distance is lighted and focused.

It might be thought that one need not bother about the lighting; that the vibrating lens might be used out of doors as well. The trouble is that the size of the image changes. As the lens moves out to shift from far to near focus, the image of distant objects, though they become blurred, also become larger; and the result in the finished film is a halo around them.

Dr. Dieterich, in 1933, devised a lens, consisting of several pieces of glass, that could change focus without changing the size of the image. In its latest form the lens has four elements, and only the second, which is concave, is moved. Its total travel is about a seventy-fifth of an inch. Mounted like the sound-producing element of a loud speaker, it is vibrated electrically,

at a speed determined by an electronic control. The best results, it is found, are obtained when the lens makes four complete sweeps for each picture. The sharp images mask out the fuzzy ones, with which they exactly coincide, and the film shows near and distant objects all sharply defined.

But a sound film, even though it be in color and taken with such a device, is still only a picture when it is projected. To achieve complete realism it would have to be in stereoscopic relief. This has been done very expertly, as those who saw the stereoscopic film in the Chrysler exhibit at the New York World's Fair will well recall.

To take a stereoscopic film, a double camera, the lenses located as far apart as the two eyes, must be used. One film will show the right eye's view, the other the left eye's. The trouble comes in letting an audience view these films, for when both are projected together the result is merely a blur; each eye sees both pictures. To obtain relief, the right eye must see only the right picture, the left eye the left. One method used in the past to do this required the use of colored glasses, a red one over the right eye, a green one over the left. Similarly colored filters are placed over the lenses of the two projectors, and each eye sees the picture in its respective color.

The Chrysler film used Polaroid screens to do the same thing, eliminating the red and green filters which would have interfered with the colors of the picture itself. These screens are made of a material which polarizes light. Unlike ordinary light, which vibrates up and down, from right to left horizontally, and in all other directions, polarized light vibrates in but a single plane. To the naked eye it seems no different from unpolarized light. But the screen acts like a picket fence and, in one position, only vertical vibrations can get through. If, beyond, there is another such fence with the pickets upright as in the first, the vibrations can get through this freely. But if the second fence has the pickets horizontal, this stops the waves that got through the first and none penetrates the combination.

Over one projector, in the New York showing, was placed a Polaroid screen that polarized its light in a vertical direction, while light from the other was similarly polarized in a horizontal manner. Members of the audience were provided with "glasses" made of the polarizing film and oriented in the same way. When these spectacles were used to watch the film, each eye saw only the proper picture, and it appeared solidly in three dimensions.

Still better is a system that would give similar results without having the audience bother to hold special viewing glasses before their eyes. Dr. Herbert E. Ives, physicist of the Bell Telephone Laboratories, son of Frederic E. Ives, the color photography pioneer, devised a means of doing this. The picture was taken with a battery of cameras, showing the view from a number of angles, and projected, from the same number of projectors, from behind the screen as in the Translux Theaters. Between screen and audience were a series of vertical glass rods which acted as lenses—but bent the light rays in a horizontal direction only. They sent to each eye the proper view. This process gave an image which actually appeared solid; that is, one could move the head from side to side, and see around the objects depicted.

The complexity of the process has hampered its application, although a couple of years ago reports reached the United States that a theater using this idea had been opened in Moscow. Full details of the process, however, never reached us though it was said to be extremely effective, as well it might be. A special production was made to demonstrate its advantages. One scene showed apple blossoms falling from a tree, and it was said that they seemed to be descending into the audience.

Perhaps this will be the picture of the future. Then photography will have obtained well-nigh perfect realism. Edison's dream of a performance in the Metropolitan Opera House, appearing exactly like the original, though with actors long since dead, may thus be achieved.

XVIII. *New Sounds in the Theater*

A few years ago an audience in Constitution Hall in Washington heard one of the strangest symphony concerts on record. The music was by the Philadelphia Orchestra. Each instrument was heard in its proper place on the stage—right, left, forward or rear. Everything was perfectly natural—except that there was no orchestra! Yet this was no recorded concert; at the very moment the orchestra was actually playing, but in its home auditorium, the Academy of Music in Philadelphia.

This was the first demonstration of the Bell Telephone Laboratories' system of "stereophonic" transmission of sound. Three microphones were placed at strategic points among the musicians, and each, through its own wire channel, fed a loud-speaker in a corresponding position on the Washington stage. Thus, for the listeners, the particular combination of volume from the three speakers for each instrument gave the effect of sound coming from some particular position on the stage. Other demonstrations of stereophonic possibilities were given. A stage hand called for a hammer, an assistant slid it across stage to him. In Washington it was possible to hear the two men, one on one side, the second on the other, and also to follow the hammer on its journey—taking place more than a hundred miles away.

To give even greater flexibility to the effects produced than would have been possible with the orchestra alone, Leopold Stokowski, the orchestra's director, sat in a box in the Washington hall, manipulating controls for the speakers. In this way he could effect a range in volume much greater than anything the orchestra could accomplish directly. For example, with all instruments playing, the intensity could be reduced to a pianissimo softer than that of a single muted violin. Or

crescendi could be developed to a fortissimo greater than the musicians themselves could ever produce.

In later demonstrations the scientists of the Bell Laboratories produced the same effects in recorded concerts. The sounds from each microphone are recorded on film as with sound movies. The film, instead of a single sound track, has three, and also another control track which regulates the output of the speakers.

Something comparable was devised for the first presentations of Walt Disney's cartoon feature picture *Fantasia*, with the aid of Radio Corporation of America engineers. Mr. Disney is said to have had the idea first when, several years ago, he watched a bee buzz off the screen in one of his own cartoons. The finality of the disappearance bothered him and he felt that it should have been possible to have the bee around even if it were not required on the screen.

About this time a Mickey Mouse short, based on the ballad by Goethe which in turn had inspired Paul Dukas' music *The Sorcerer's Apprentice*, was being made in the Disney studios. The music was to be conducted by Stokowski. As it progressed, it became more elaborate, finally being expanded into a full-length feature, and with other musical numbers added. The recording of the music was done in the Academy of Music in Philadelphia, by the Philadelphia Orchestra under Stokowski's direction.

An RCA statement described as follows the technique:

For every group of loudspeakers used in the theater there had to be a separate source of sound synchronized with the picture. So when Mickey Mouse appears on the right, a control mechanism switches on the loudspeaker directly behind him and veers the sound to another speaker when he moves.

Stokowski directed as he would ordinarily, and the orchestra played with its familiar fire and skill. But there all convention ended. For the music had to be divided up in such a way that later it could be blended at will and reproduced through the required loudspeaker—wherever Disney wanted it.

To do this, the orchestra was divided into five sections—strings,

basses, woodwinds, brasses and percussions. Each section was covered by three microphones and recorded on a separate track. Also, there were three additional straight recordings, two on film, one on records, and a beat track giving the beat, entrance cues, etc., which the cartoonists used to synchronize the action to the music. Each of these tracks could be blended in any way with any other track or combination of tracks, so that actually any single instrument, section or the whole orchestra could be heard coming from any one point on the screen.

It worked like this: During a recording, the music approaches a clarinet solo. The Disney engineer, sharing the podium with Stokowski, signals the engineer in charge of the woodwind section to look out for the clarinet, and gives him the level at which it is to be recorded. In the final blend, the clarinet's loudness is played up or played down depending upon what purpose it fulfills in the finished production. And it may be heard in the theater from any desired loudspeaker.

The Bell Laboratories' stereophonic sound, and the RCA "Fantasound," as the system used for *Fantasia* was dubbed, are both adaptations of the electronic tubes described earlier in this book. But both involved a significant departure from most other uses of these devices in connection with public performances. The usual public-address system, with its microphone, amplifier and loud speaker, is used to overcome shortcomings either of the auditorium or of the speaker himself. If he had a voice sufficiently powerful, or if the acoustics of the room were good enough, in most cases such a system would not be needed. Stereophonic sound and Fantasound did more than this—they actually made possible effects that could not otherwise have been obtained.

The most important research program in this field, however, is one that has been conducted since 1930 by Harold Burris-Meyer and his associates at Stevens Institute of Technology in Hoboken, N.J. Many musicians and theatrical people have co-

operated, while funds have been furnished by the Rockefeller Foundation and the Research Corporation. Part of the work has been done at the Metropolitan Opera House, though early in 1942 it was necessary to remove the equipment to use it on a war problem, and plans for using the system in the performance of various operas had to be postponed.

In a WGY Science Forum radio talk, Mr. Burris-Meyer said:

Most sound controlling devices have been mechanical. The human voice is a mechanical gadget. And all the conventional musical instruments are pounded or blown or scraped to make them work. And, satisfactory as they are—the tympanum, the pipe organ and the human voice—they never quite make or control the sound as completely as the composer would like to control it. The flute can only play so softly and still operate. If you want a softer note, it has to be played by a stringed instrument. The violin can only play so loud, the voice can only sing so high, and no mechanical sound source makes the sound come from any place except where the instrument is. It doesn't take much artistic imagination to see that if you can make the music come from wherever you want it to, your artistic scope is a good deal greater than if the music comes from a place which you can't help.

Also, it is artistically advantageous to have a dynamic range, that is, the distance between soft and loud, which is considerably greater than any mechanical instrument can make; and it is nice to have the sound come from far away or near at hand if that is required. Now the musicians did almost all that was possible to control their medium by mechanical means some time ago, and they were pretty badly stymied when electronic devices came along.

By electronic means it is possible to make the sound do anything the artist wants it to do. It is possible to make it come from where you want it to; the Angels' Chorus in *Faust* can come from the chandelier; Ariel in the *Tempest* can move about unseen above the audience; the celestial orchestra in Sidney Howard's *Madam, Will You Walk?* can fill the whole theater. The sound can be made as loud or soft as is requisite. The flute can play music normally assigned to a muted violin; the shout of the crowd in *Elijah* can rattle windows across the street. The theater can have any reverberation characteristics which seem appropriate to the sound. The church scene in *Faust* can sound as reverberant as is appropriate to a church; the scene in the garden can sound as non-reverberant as is appropriate to a garden.

That is, in addition to the very complete control of lights and mechanical features available for dramatic producers, complete control of sound also is now possible. This does not mean merely the familiar sound effects of thunder, rain, airplane motors, or pounding hoofs. Those can be produced too; but Mr. Burris-Meyer objects very strenuously to calling his work "sound effects." He feels that the entire auditory component of a show should have enough unity and dramatic significance to form a complete work of art by itself.

In the spring of 1941, at the Stevens Theater, he presented the *Second Sound Show*. The first had been given seven years earlier, and both were intended to demonstrate the progress of that research. The show consisted of excerpts from various plays which brought out the effective use of sound-control methods. One was Shakespeare's *The Tempest*, a play most difficult to present if any effort is made to follow the implied directions. "The isle," on which the action is laid, says Caliban in Act III,

. . . is full of noises,
Sounds and sweet airs, that give delight and hurt not.
Sometimes a thousand twangling instruments
Will hum about mine ears; and sometimes voices.

An important character is Ariel, the "airy spirit," who appears, generally invisible, and departs

. . . to fly,
To swim, to dive into the fire, to ride
On the curl'd clouds.

Surely the illusion is given a severe jolt when, in such a part, appears a human being of flesh and blood, obviously just as corporeal as the other characters or any of the audience. He hardly obeys Prospero's injunction:

. . . be subject
To no sight but thine and mine; invisible
To every eyeball else.

In the Stevens production, on the other hand, we saw what Shakespeare must have had in mind as an unapproachable ideal when he created the part. Prospero is on an apparently empty stage, conversing with Ariel, whose voice comes from the other side. While the conversation continues Ariel, as we might expect, flits around the theater. His voice comes from the rear, then from above—apparently he is flying about over the heads of the audience. And the source of the music from his pipe and tabor moves about with him.

Another scene was from *A Midsummer Night's Dream*—the one in which Titania, the fairy queen, temporarily bewitched by her husband, Oberon, falls passionately in love with Bottom, who then has the head of an ass. Before and after this Bottom speaks with his own voice. But when he has the head his voice, though understandable and still resembling his normal voice, has the quality of an ass's bray.

This involves two techniques. First, there is the remaking and recording of the actor's speech. (The sounds made by a jackass of the four-legged variety have a much greater range of pitch than the human voice.) Then, when the recording was played, the control of perspective was used, shifting from one loudspeaker to another as Bottom moved about the stage, so that throughout he seemed to be the source. This control of auditory perspective was also used to make the source of Ariel's voice move about the theater.

Remaking the voice was accomplished with a device called the Vocoder, which was developed by Bell Laboratories' engineers. It was the ancestor of the Voder, the device for making synthetic speech that was demonstrated at the New York and San Francisco World's Fairs. With the Vocoder, the human voice may be made to modulate any sound that can be brought into the studio: the sound can be remade to have any desired pitch or quality, or any range of pitch. A waterfall, thunder, an explosion, a sound of falling bricks, all can be made to talk. Somewhat similar in effect is the Sonovox of Gilbert Wright, used in the Disney studios. This transmits any de-

sired sound to the throat of a person who can talk or sing, the transmitted sound serving as a substitute for the sound that would normally be produced by the singer's larynx. (This made it possible for the locomotive to sing its song in *Dumbo*.) And still a third device is one which is due to Professor F. A. Firestone of the University of Michigan. Through a glass tube a sound is piped to the base of the performer's tongue, where it can be used as a source of song or speech. One person, without using his vocal cords, can sing an octet with this apparatus!

One of the most effective uses of the remade voice in the *Second Sound Show* at Stevens was the opening scene in *Macbeth*. Mr. Burris-Meyer explained, in his WGY talk, that they wanted "to see if the witches could be made into twentieth-century demons which are visible only to Macbeth, but cast shadows as they move about the fire, which the audience can see. Three pleasant voices were rebuilt so that their owners would never know them. One was made higher than the human voice can go, one was given a quality which is a cross between a rock-crusher and a whiskey baritone, and the third was transformed into a basso. For the production, the dialogue was played against a background of the scherzo of Prokofieff's *Concerto in D Major* for violin and orchestra." The results were most successful.

This was the sequel to an earlier accomplishment. "Back in 1934," said Mr. Burris-Meyer, "we set out to make the Ghost in *Hamlet* sound like a ghost. So we built a voice which was pretty sepulchral and dubbed it on to an ectoplasmic figure, and made quite an impression. The technique of making the voice consisted in suppressing some of the voice frequencies and emphasizing others. It wasn't long until the same idea adapted to radio as a sort of juke-box voice became part of the standard radio bag of tricks. The voice of the Ghost came from a translucent figure moving about the stage."

Reverberation is one of the most important qualities in which halls differ acoustically, and means have been devised for its control. The Stevens Theater is the assembly hall of an

old building, with very little of the qualities of a great cathedral. Yet in the church scene from Gounod's *Faust*, where Mephistopheles summons Marguerite, reverberation, with its relative the echo, was introduced, especially in the case of the Mephistophelian voice. And in another demonstration of reverberation control, a special recording of the Toccata in F from Widor's *Fifth Organ Symphony* was played with the reverberation characteristics of the Church of St. Sulpice in Paris, where the composer was organist.

This is achieved with a modern form of a device called the telephone, invented some years ago by Professor V. Poulsen of Copenhagen. Sound was recorded by magnetizing parts of a long wire, and reproduced with a device in which the magnetism of the wire as it rolled through controlled the motion of a diaphragm. Now this is made better with electronic tubes, and great faithfulness of reproduction is obtained. The advantage is that by passing the wire through a strong, constant, magnetic field, the old record is wiped off and the wire is then ready to receive a new one. For reverberation effects, an endless wire is run through the machine. The sounds are recorded and played back once or several times, a fraction of a second apart, and fed into the circuit along with the impulses from the original sounds. The interval between the repetitions, the number of times they are heard, and the decrease in volume in each are all factors that may be varied, so as to reproduce the reverberation of any desired building, real or imaginary.

One of the first things the Stevens experimenters found was that the sound intensity affects the posture of the audience. They can be made to sit up straight, to move forward, or to relax, merely by varying the volume.

"With present-day audiences hardened by much theater-going," Mr. Burris-Meyer has said, "an emotional response to a dramatic episode must be strong indeed if it is to be physiologically observable or measurable. Any device by which it is possible to achieve an obviously strong emotional response may constitute a powerful tool for the artist in the theater."

However, as he later found, the sound does not actually need to reach extremely high intensity in order to produce the impression of great loudness. All you have to do is to shake the building itself, mechanically, from a direction different from that in which the sound is actually coming. A very loud sound does shake the building; therefore if you shake the building when any sound is made, the audience thinks it is loud even if it isn't!

Experiments were also made with changes in frequency; that is, in the pitch or "shrilness" of the sounds. One remarkable effort was in a play by Elmer Rice, called *Adding Machine*, in the "brainstorm" scene. "We tried to achieve expressionism in sound, in conformity with the idiom of the play," Mr. Burris-Meyer later explained, "and drive the audience crazy as the principal character lost his reason. We almost did. And the principal device was an almost pure tone warbled and raised in frequency and intensity for about thirty-two seconds while the stage spun around and Mr. Zero turned killer. The *Adding Machine* episode showed that you could use control of frequency very simply to achieve the dramatic objective of the playwright."

Many types of equipment are used in this work. Some are standard devices which have been adopted and adapted. Others are units particularly designed and built. There are loudspeakers and microphones galore; there are electrical controls which can regulate the speakers through which sounds from particular microphones are produced, and to permit gradual fading from one to another. There are the devices for recording sound on disc, film and magnetized wire. And there are other novel sound-producing devices which feed into the circuits.

One of the most versatile is a "thunder screen." It is a square frame of wood to which a copper fly screen is attached. To the center is fastened a pick-up like that of a microphone. Rubbing or tapping the screen energizes the pick-up and produces a variety of sounds, which of course can be remade with the rest

of the sound equipment. Sometimes the screen is stroked with a cloth. Again it may be hit with a stick, or perhaps touched lightly with a small brush. It will make a realistic airplane, which, with proper control, seems to be circling around the ceiling, then flies off in the distance over the stage.

In a scene in the *Second Sound Show*, from Eugene O'Neill's *The Emperor Jones*, the thunder screen was used as the jungle drum that throughout this impressive play, is heard in the background gradually getting louder. In this production it started with very low notes, so deep that they could be felt rather than heard. This established the cadence before the actual sound was noticeable. The effect of this varied. Some said they did not notice it, while others were conscious of the beats from the start. One actor who played the part of Smithers claimed not to notice it, but it was observed that he gave his lines in cadence with the beats—whereas in an ordinary production he showed no such rhythm.

Among the many artists who have co-operated with Mr. Burris-Meyer in his work is Paul Robeson, distinguished baritone. With him a technique was developed which he has employed regularly in recitals, while others have used it too. Unlike the other parts of the Stevens researches, this is for the benefit of the artist rather than for the audience, though they benefit indirectly as they enjoy a concert more the better the artist does it. Singers have often noticed that they sound better to their own ears when singing in the bathroom than on the concert stage. The reason, naturally, is that the hard walls of the small room give high reverberation, and they actually hear themselves. In a large hall the voice is lost, and singers cannot form a good idea of the way they really sound.

The Robeson technique uses a concealed microphone with a loudspeaker just off-stage. This is highly directional; that is, it can only be heard in the direction toward which it is pointed. It is aimed at the artist, so that he can hear himself as if he were singing in his shower, but the audience is unaware of the loudspeaker and hears only the direct sounds. Because of its

synthetic character, Mr. Robeson dubs the outfit "Synthea." Somewhat comparable was an installation tried out in the Metropolitan Opera House to enable the performers in the up-stage areas to hear the orchestra as well as the audience does.

With Mr. Burris-Meyer, and the equipment that he used, serving in a war job, it became unlikely that there would be any further development of his methods for the present. For the future, he has said:

It means that speech, prop sounds, background music, all the sound in the show, if planned according to the principles of musical composition, can have many times the dramatic power they now have. We have made a number of experiments to test the theory. They have been exciting. A production in which the whole auditory component is composed as music has all the advantage of opera minus the heavy soprano or the limitations of the human voice or the musical instrument. As a result the limitations on the auditory component of the show are off. The players may speak with the tongues of men and of angels. With sound you can compel the audience to laugh, to weep. You can knock them off their seats, you can lay them in the aisles, you can make them believe what you will. It has been done. One day we shall see the production of *The Tempest* Shakespeare envisioned, and a *Götterdämmerung* which would have satisfied Wagner.

XIX. *Into the Atom*

A new kind of chemistry has been born in recent years. It is a kind of chemistry which sometime may well make our present-day chemistry—the sort of processes described in previous chapters, of rearranging molecules and atoms to make gasoline, rubber, explosives—seem quite old fashioned. This chemistry penetrates to the heart of the atom. It has realized the ancient dream of the alchemists, a dream which chemists of the nineteenth century thought hopeless.

Whereas the alchemists failed to change lead or some other “base” metal into gold, modern science has done it—in fact, has changed many elements into others. The fact that the cost of making the change far exceeds the value of the elements you get in no way detracts from the significance of the achievement. As this modern alchemy develops, as we learn more about its principles, its value to mankind will be infinitely greater than merely making lead into gold with some mystic “philosopher’s stone.”

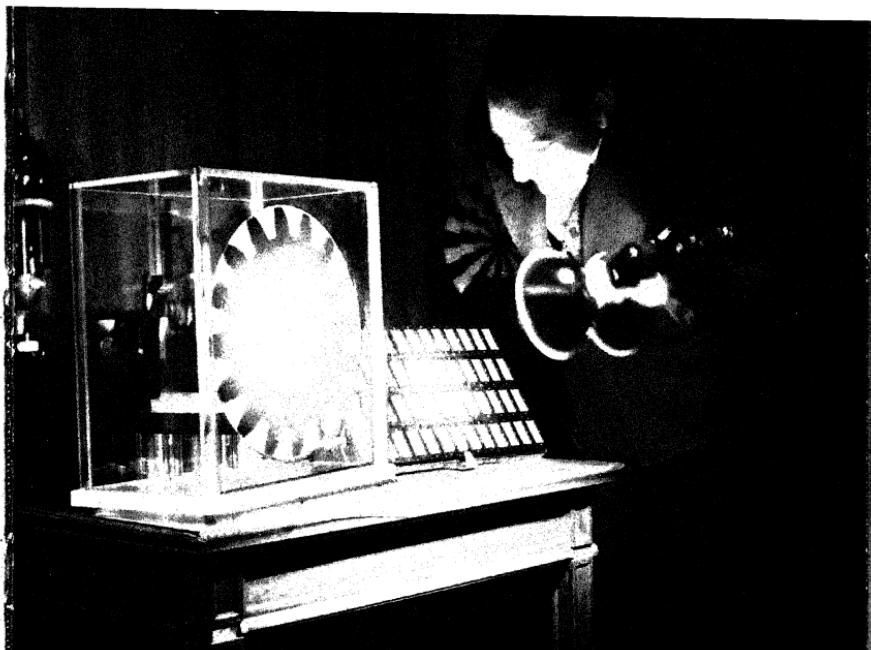
The word “atom” means *something which cannot be divided*, and that was the past century’s conception of it; the atom was the fundamental particle. There were a number of different kinds, one for each element. There could be no such thing as “atomic structure,” for how could a particle incapable of subdivision have any structure? An atom of hydrogen, of sodium, of any element, was thought to be always the same. In chemical reactions you might shift the atoms around, making new molecules. You might take a sodium atom away from the atoms of hydrogen and oxygen with which it is associated in caustic soda, hitch it on to a chlorine atom taken from a union with hydrogen in hydrochloric acid. The new pair, sodium and chlorine, is common salt. But in this process the atoms have not changed—they are the same throughout.

Experiments such as those of J. J. Thomson, however, which revealed the existence of the electron, showed that the atom is a complicated thing—at least as much so as a grand piano, because it is capable of giving out various “notes,” which show up as light of different colors or wavelengths.

The modern idea of the atom goes back to the theory proposed in 1913 by Niels Bohr, a Danish physicist then working with Sir Ernest Rutherford at Cambridge University. We can illustrate his concept with the simplest atom, that of hydrogen. There is a nucleus, consisting of a unit charge of positive electricity, and revolving around this a negative unit charge, or an electron. Normally, the electron moves in an elliptical orbit around the nucleus, like a planet around the sun. However, there are other possible orbits, farther out from the nucleus, in which the electron can be made to move when energy is applied to it. But then it tends spontaneously to return to its favorite orbit, and as it does so it gives out the energy again as a burst of radiation, or light either visible or invisible. There are a number of possible jumps that the electron may make, and each shows a characteristic note, or wavelength. Other atoms are more complicated, with more electrons and more orbits, so they have more possible jumps, and more lines in their spectrum, in many cases.

Nowadays physicists no longer picture the electrons as little planets revolving around in nice, precise orbits. Rather have the orbits themselves become rather hazy regions in which, probably, the electron will be found, while the electron is not a definite entity either, but a sort of waviness.

However, the atom has been shown to be a complicated thing. We might compare it with a watch, a complex assemblage of mechanism surrounded by a metal case. The atom does not have the metal case, but it does have a shell, made up by the field of force which surrounds it. Ordinary chemistry does not penetrate this shell, but our new chemistry does—it gets into the heart, or nucleus, of the atom.



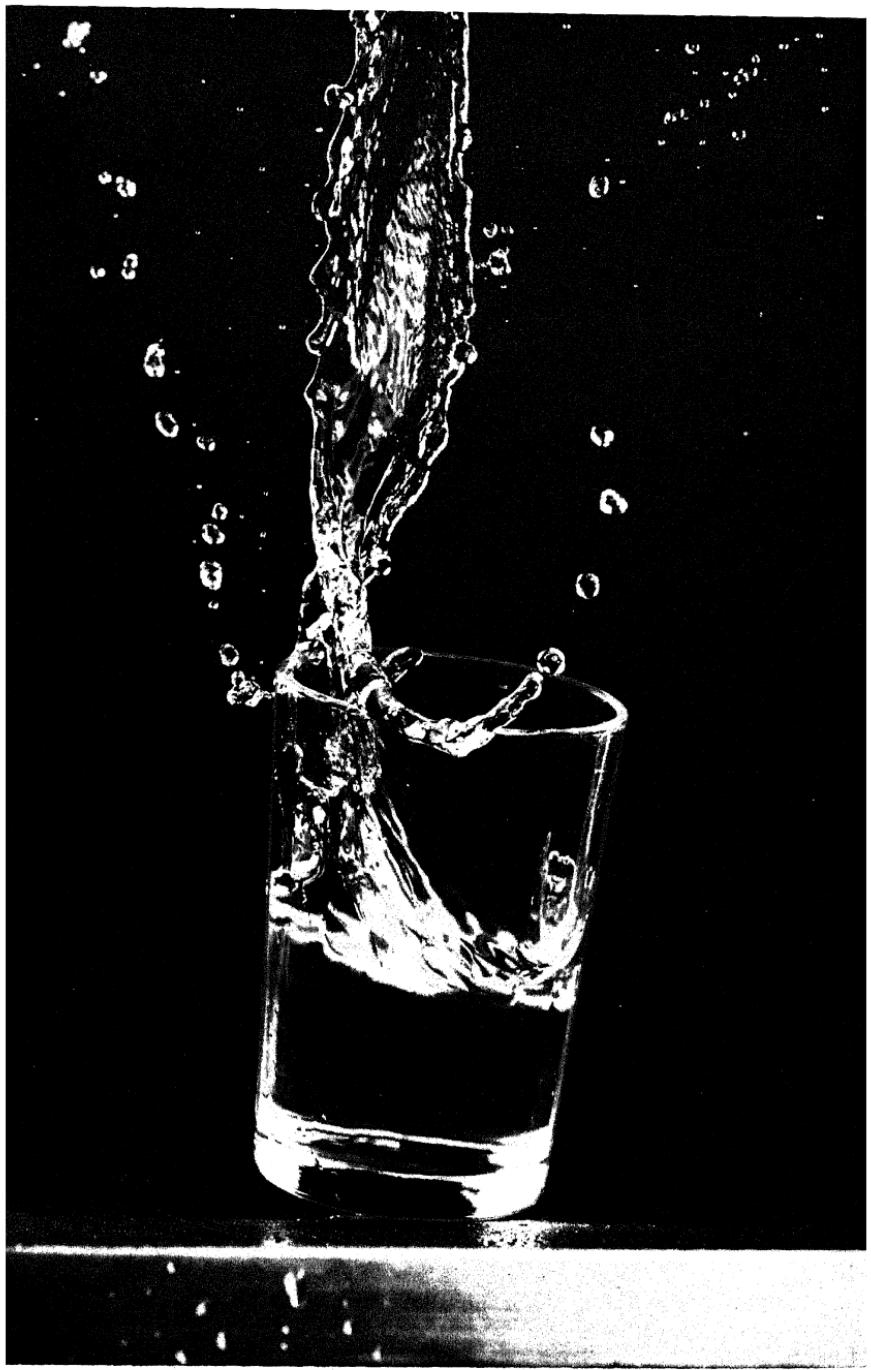
POWER FROM SUNLIGHT

(see page 274)

CHEMICAL LIGHT

(see page 224)

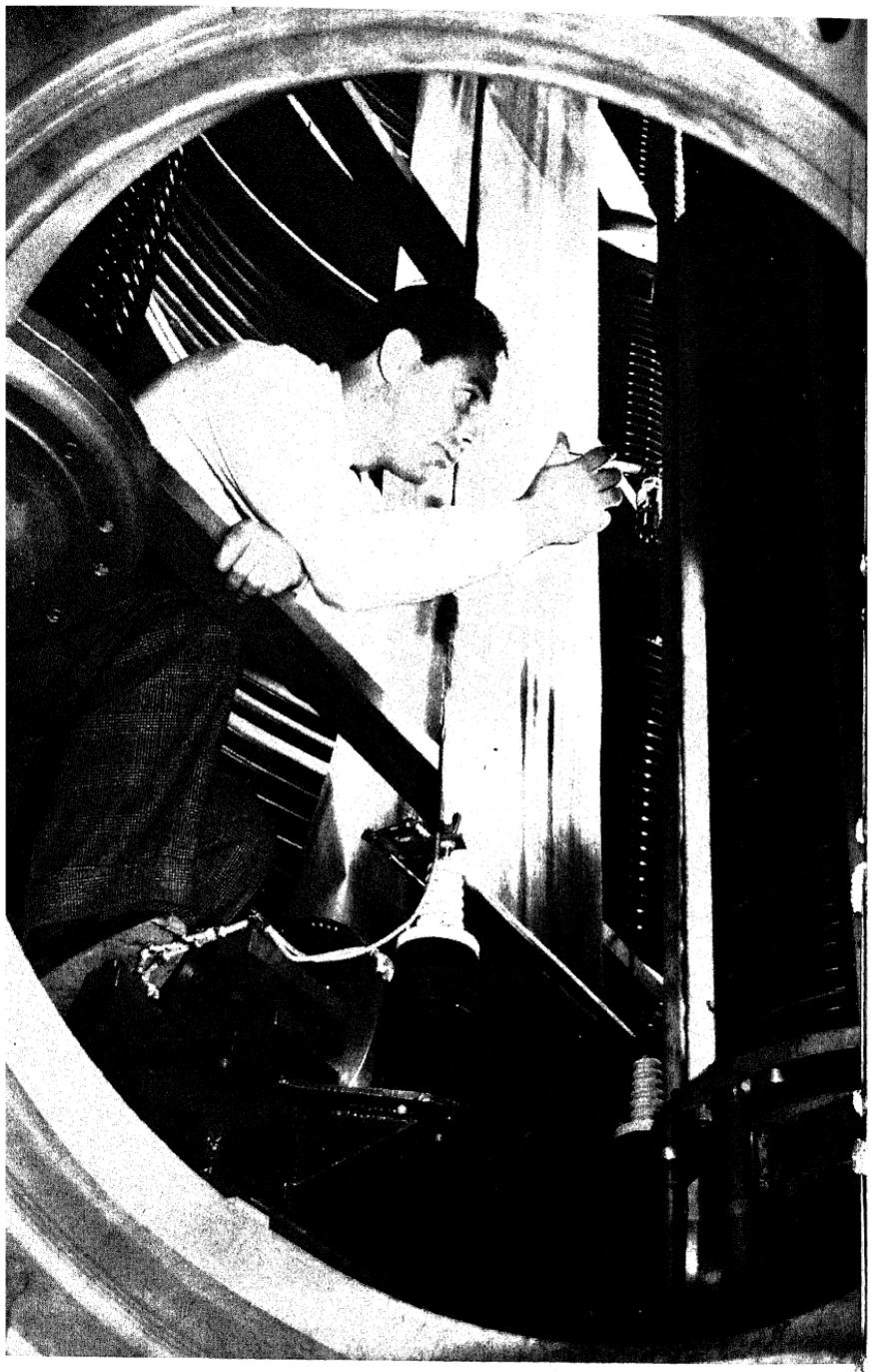




STROBOSCOPE PHOTOGRAPH OF A FALLING GLASS OF WATER
(see page 256)



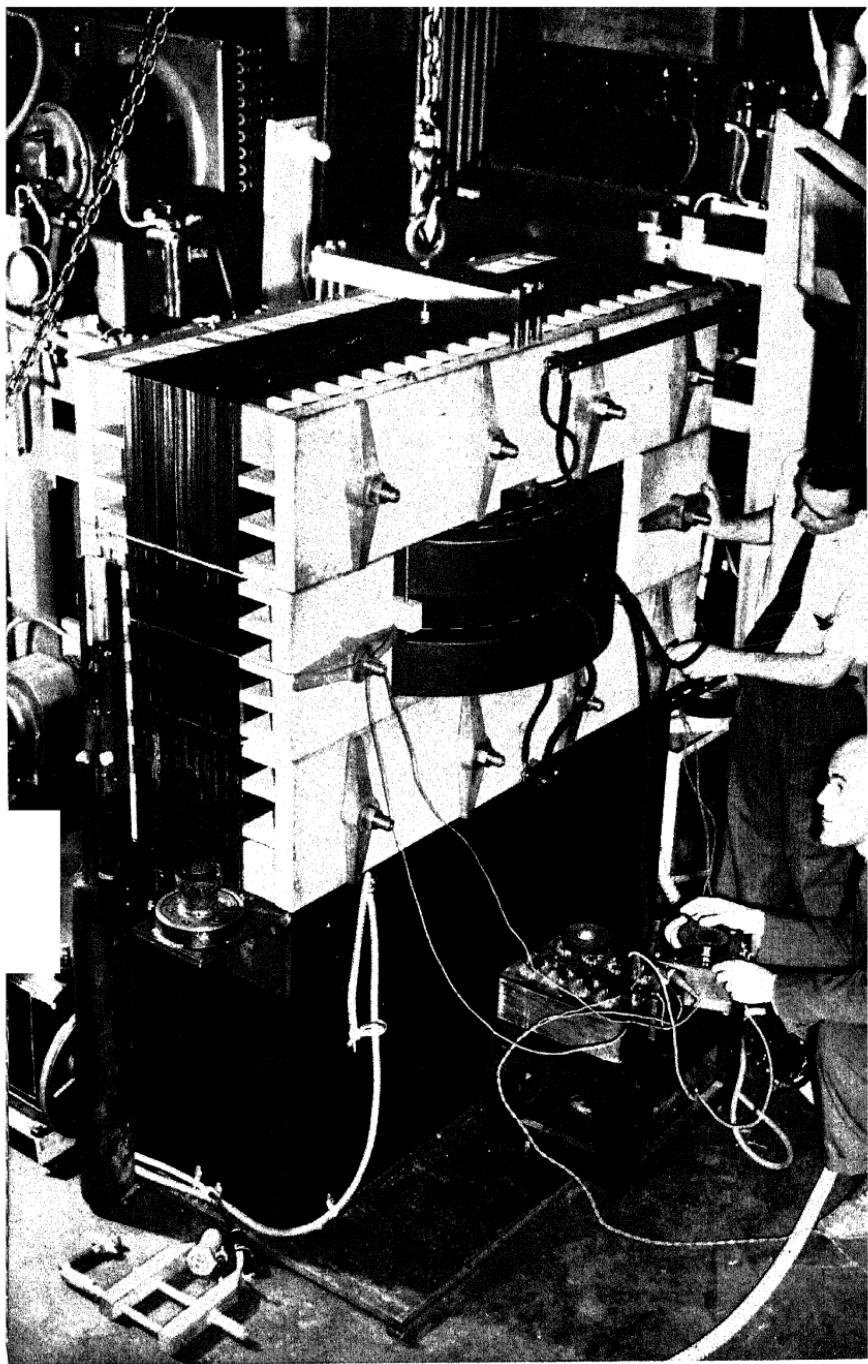
HUGE TEST TUBE FOR SEPARATING ISOTOPES
(see page 258)



INSIDE A VAN DE GRAAFF GENERATOR
(see page 259)



CYCLOTRON UNDER CONSTRUCTION
(see page 260)



20,000,000-VOLT ELECTRON WHIRLPOOL
(see page 265)

The physicists' most powerful artillery was needed to get through the shell, and reach the nucleus. "Artillery" is used advisedly, for the process actually consists of firing bullets at the atom; not ordinary bullets, but bullets which are pieces of atoms themselves, of a size comparable with the atoms to be smashed. The first to be used were those constantly given off by radium; nuclei of helium atoms, also called "alpha particles." These have energies high enough to penetrate the forces around the nucleus, provided you aim them right.

Since you cannot see either the atoms you are trying to hit or the bullets with which you are shooting, aiming is out of the question. But if you are in a dark cellar in which a swarm of bats is flying, and you have a machine gun which you spray around, you will occasionally hit a bat. This is in effect what Sir Ernest Rutherford did at Cambridge University in 1919, when he accomplished the first actual transmutation of one element into another and realized the alchemist's dream.

His apparatus was a box containing nitrogen gas. Inside was a bit of radium, the machine gun, while the nitrogen atoms were the bats. At one end of the box was a "window" of thin silver. Outside this window was a screen of zinc sulfide, a material which glows with momentary starlike points of light every time an alpha particle strikes. But no particles struck it, for the silver window was just too thick to let them pass.

Occasionally a spark of light did appear on the screen! Here was a particle that came from the box with more energy than an alpha particle. Rutherford studied these new particles in various ways—by measuring the effect on them, for example, of a magnet—and established that they were nuclei of hydrogen atoms, or what soon came to be called protons. What had happened was that an alpha particle had squarely hit the nucleus of a nitrogen atom, and had, indeed, been captured by it. A proton had been given off. But the alpha particle itself consists of two charges—two protons. Hence the nitrogen nucleus had one more proton than before—it had eight instead

of the seven which it normally carried. However, the element with eight protons in the nucleus is not nitrogen—it is oxygen! Not ordinary oxygen, but a form in which the nucleus is one unit heavier than the ordinary kind.

Most of the elements have been found to exist in these several different weights, and the separate forms are called "isotopes." Ordinary oxygen, which makes up a fifth of the air, contains 99.76 per cent of an isotope of weight 16, a very small amount of weight 17 (the kind that Rutherford produced) and a fifth of a per cent of weight 18 as well. But the transmuted nucleus of heavy oxygen contained not only one more proton than the nitrogen nucleus from which it was produced: the alpha particle also left two neutrons. These are particles that another Cambridge scientist, James Chadwick, had discovered in 1932. With the same mass as the proton, but having no electrical charge, the neutron fitted very conveniently into concepts of atomic changes.

It explained, for example, why two isotopes can have different weights yet be the same element. The number of protons in the nucleus (the same as the number of electrons in an element in its normal state) determines what the element is. Thus, all nitrogen atoms have seven protons, and all oxygen atoms have eight. Ordinary oxygen has in addition eight neutrons, but its heavy isotopes have either nine (for weight 17) or (to make weight 18) ten.

There is also a heavy form of hydrogen, called "deuterium," which Dr. Harold C. Urey of Columbia University discovered in 1932. Ordinary hydrogen contains it in the proportion of about one part in five thousand, but it can be separated into a nearly pure state. Its nuclei, called "deuterons," have proved the most effective atom-smashing bullets thus far.

A deuteron consists of a proton, like the nucleus of ordinary hydrogen, plus a neutron, making it twice as heavy. Because it has a single charge, it is just as easily fired by electrical forces at the nucleus as is the solitary proton. And when it gets close to the nucleus of the atom under attack, the neutron is released

and sent in to perform its mission. However, neutrons by themselves, and also protons, unaccompanied, are used as atomic bullets as well.

Protons were the projectiles which Cockcroft and Walton used in 1932, speeding them up with energy equivalent to 700,000 volts and aiming them at lithium. Nuclei of helium atoms—alpha particles—were given off. This was actually the first success at atom-smashing with laboratory apparatus, since the alpha particles that Rutherford had used were produced by natural processes taking place in the radium, and not under the control of man.

To advance further required the use of more energetic particles. Higher voltages were needed to send the bullets on their way. Two machines have been used to do this. One is the Van de Graaff generator. Essentially, this generates electricity in the same way that you may generate it on a winter day, when you scuff your feet on a rug and draw a spark from a light fixture or some unsuspecting person's ear. In rubbing over the rug, you accumulate an electrical charge. The central part of the Van de Graaff machine is an endless belt of insulating material on to which an electrical charge is sprayed. The upper end of the belt is inside a hollow metal sphere, and its motion carries the charges to this sphere. There they are drawn off; the sphere itself accumulates the charge, while the belt goes down again for more. When the charge is great enough, it can overcome the natural resistance of the air; and a spark jumps to near-by grounded metal. By enclosing the entire apparatus in a tank, with gas under pressure, the resistance is increased and higher voltages—up to 5,000,000 volts—may be obtained. Then these voltages may be used to accelerate positive or negative particles for atom-smashing experiments. Several of these Van de Graaff generators have been installed in great research laboratories.

The other and even more popular atom-smashing weapon is the cyclotron, invention of Dr. Ernest O. Lawrence of the University of California. It reaches higher voltages, but they cannot be as accurately controlled. We can think of it as a sort of atomic sling-shot—the kind that David used to slay Goliath, when he whirled a stone around his head in a sling, then let it fly when it had gained sufficient speed.

In the chapter on electrons we saw how Dr. W. D. Coolidge cascaded electrons to speed them to high energies. By applying voltages of perhaps one hundred thousand several times in successive steps, the particles were given successive boosts and attained energies equaling the sum of these steps. With a device called the linear accelerator the same thing can be done with protons, and this device has been widely used in atom-smashing experiments. In fact, in 1931 Lawrence himself, then thirty years of age, speeded particles to a million and a quarter volts.

But the linear accelerator gets longer and longer as its power is increased, and this imposes a limit beyond which it is too unwieldy to use.

Then Lawrence turned to the sling-shot idea. The cyclotron was the result, winning for him the Nobel Prize in Physics in 1939, the last given. Electrons from a hot filament hit molecules of a gas, such as hydrogen; and protons (or deuterons if the gas is heavy hydrogen) are formed inside a chamber that is well evacuated, for very little gas is needed to supply the bullets. Also in this vacuum chamber are two hollow D-shaped electrodes, called "dees." Cut a pill box into two semicircular halves, separate the halves slightly, and you have a good model of these dees.

The dees are connected to, essentially, a powerful short-wave radio transmitter, giving a rapidly oscillating electrical current. Each dee is continually changing from negative to positive, then back again, many times per second, and the two dees are always oppositely charged. Our proton, then, knocked out of a hydrogen atom by an electron, has a positive charge; it is at-

tracted to the negative dee. Since the entire vacuum chamber is between the poles of a powerful magnet, the magnetic field causes the proton to move in a semicircle, back to the opening between the dees. By this time their charges are reversed; now the other has the negative charge, so the proton is yanked across the opening with an increase in speed.

Again it moves in a semicircle, under the magnetic influence; again it comes to the gap, again the field has changed. Now the first dee is again negative, so the proton has another jerk. It goes around and around, moving in ever-widening circles accelerating each time it crosses the space between the dees. Compared with the linear accelerator, the voltage used in any one jump is small; in some of Lawrence's early experiments it was only about four thousand.

Finally our proton is traveling around the edge of one dee, then it comes within reach of a negatively charged plate which pulls it out of the dees entirely. It passes easily through a thin metal window, out into the open air where it can be used to bombard anything that happens to be in range. What happens to one proton (or deuteron) is, of course, happening to a swarm, and they all emerge as a potent beam.

The first cyclotron was only four inches in diameter, and a small magnet sufficed. But to increase the power, bigger and bigger magnets had to be used. At the University of California's Radiation Laboratory in Berkeley, of which Lawrence is director, a sixty-inch machine, with a 220-ton magnet, speeds the particles to energies of around 16,000,000 volts. More than thirty other cyclotrons are in regular use in research laboratories throughout the world; and Lawrence and his colleagues have in an advanced state of construction, on a Berkeley hill overlooking San Francisco Bay and the Golden Gate, the biggest of all. The huge electro-magnet is made of 4900 tons of steel; the beam of atomic projectiles will be so powerful that it will penetrate, it is expected, about 140 feet of air. The voltage will be between 100 and 300 million.

When this cyclotron goes into operation many now formida-

ble barriers to science's insight into the atom will undoubtedly be broken down. As the protons, deuterons, or even nuclei of helium atoms are spun around, some of them stray from the main beam, hit the copper walls of the chamber, knock neutrons out of the copper atoms, to be strewn around promiscuously. A cyclotron therefore is usually surrounded by tanks of water several feet thick, which form barriers to the wandering neutrons.

All of the effects of neutrons on the human body are not known, though they seem to have some. (Experiments have shown that they produce sterility in mice about four times as effectively as X-rays.) When in use, therefore, the cyclotron is controlled remotely from a neighboring room.

But often neutrons are desired for use in experiments. Then they are produced by bombarding lithium, beryllium, or some similar light metal with the deuterons. It was in this way, for example, that two Harvard University physicists, according to their report in 1941 to the American Physical Society, realized the dream of the alchemists; for mercury was turned into gold. The physicists are Dr. Rubby Sherr and Dr. Kenneth T. Bainbridge. No vast fortunes awaited them as a result, however, for the amounts of gold produced were so insignificant that an indirect means of detecting it had to be resorted to. Also, the gold was in the form of isotopes which quickly decayed into other elements, some in a few minutes, others in several days.

The method Sherr and Bainbridge used shows some of the ingenious tricks that science must employ in these researches. Deuterons from the Harvard cyclotron were fired at lithium, neutrons were obtained and, in turn, used to bombard mercury. Then a small bit of gold was mixed with the mercury and the mercury was boiled away, leaving the gold by itself again, except for minute amounts of platinum, which had also been formed by transmutation from the mercury. This was removed by a chemical process. When the gold was tested, it was found that it contained several new forms which behaved like radium,

spontaneously disintegrating and giving off certain kinds of radiation in the process.

Very delicate tests can be made for these radioactive atoms, tests far more sensitive than ordinary chemical procedures. Since the gold itself had not been exposed to the neutron beam, it was evident that the radioactive forms must have come from the mercury. Yet there was so little of it that tests of the mercury for gold, after the exposure had been made, would have yielded no results. But when new gold was put in, it acted as bait to draw the transmuted gold into union with it; and then the original gold and the transmuted gold could be extracted together.¹

It is in making radioactive elements artificially, however, that the cyclotron has had one of its most important applications. In fact, some have been erected with this main purpose rather than for use primarily in research into the atomic nucleus. Radium, and all the substances like it, that we call "radioactive," show a characteristic disintegration into other elements, with the liberation of one of three types of ray as they do so. In the case of radium the disintegration proceeds at such a rate that, after 1690 years, half of the original amount will be gone; at the end of another 1690 years, half of that will have disintegrated, and so on. This 1690-year period is said to be the "half-life" of radium. Some radioactive substances have much longer half-lives, while others, including most of those made artificially, are much shorter, some being measured in small fractions of a second.

Radioactive phosphorus, which is made when you expose ordinary phosphorus to the beam of a cyclotron, has a half-life of fourteen days, which is a very convenient length of time. It

¹ Ordinary gold may be made, too, but platinum is needed as the raw material. Since that is more valuable than gold, this process would have held little appeal for the alchemists. But if you fire a neutron at ordinary platinum a heavier form is created, which is not stable. It decomposes into ordinary gold, with the emission of an electron, and a burst of energy.

can be injected into the body, where it performs its mission; yet after that its activity dies away. If you were to inject radium into the body, it would keep up its activity long after it was needed for therapy, and would then do considerable harm. These radioactive elements behave chemically just like the same elements in the customary form, and in the body they behave the same way too. The phosphorus is deposited in the bones, and that makes the radioactive form effective for treating leukemia, a disease in which the white blood cells, necessary in moderate amounts for combating infection, run away and overproduce. These cells originate in the bone marrow, so, when the radioactive phosphorus is deposited in the bones, it is just where it is needed for the greatest effect.

Another important use of artificially radioactive elements is as "tracers." Botanists, for example, have found them useful in studying the physiology of plants. Suppose that you want to trace the path of phosphorus through a plant's anatomy. Phosphorus goes in at one place, and is later found elsewhere; but how can you be sure that these are the same atoms? By making them radioactive, the atoms can be tagged. That is, radioactive phosphorus is formed, and mixed with the plant's nutrient. As the radioactive atoms reach various leaves, for example, they can be detected. The beta rays, really electrons, which they give off, will write their autograph on a photographic plate. Or another form of detector, called the Geiger counter, will reveal their presence by flashes of an electric lamp connected to it, or by clicks in a loud speaker. Similarly, radioactive tracers can be fed to animals, in studying the operation of their bodies.²

Radioactivity can be induced in other ways than with the cyclotron. In fact, it was first accomplished with a natural source, and there is a most appropriate family connection here.

² Nearly all of the 92 elements have been made radioactive, some in several forms, so that there are more than 350 radioactive isotopes which have been reported since this work began in 1933.

Madame Marie Curie, and her husband, Pierre, discovered radium in 1898. It was in 1933 that their daughter Irene and her husband, Frederick Joliot, discovered artificial radioactivity; and they used the rays from polonium (one of the other radium elements which Marie Curie had also discovered) to provide the rays. When they employed alpha rays from polonium to bombard a piece of aluminum, it gave off other rays which proved to be positrons—particles like the electron, but carrying a positive charge. Even after the bombardment was terminated, the aluminum continued its radiation, and this gradually weakened, in the same manner as the rays from natural radium gradually weaken.

Then Enrico Fermi, an Italian physicist who is now at Columbia University, one of the galaxy of brilliant scientists that America has secured as a result of Axis shortsightedness, showed the effect of slow neutrons. He made neutrons by shooting alpha particles at beryllium powder; but these directly did not have an effect. However, when he passed his neutrons through a substance such as paraffin and reduced their speed, they became much more effective. This seems contradictory, but it has a reasonable explanation. When the bullets tear past the atomic nucleus at full speed, they are there such a short time that they have little opportunity to be influenced, and they continue in an uninterrupted path. But when they are moving slowly, there is more time in which the attraction of the nucleus can pull the neutron in to do its work.

Electrons also can cause elements to become radioactive. This has been shown in the General Electric Research Laboratory with a device known as the induction electron accelerator, in which, with electrons speeded to energies of 20,000,000 volts, copper has been transmuted to a radioactive form.³

³ The electron accelerator, was developed by Dr. Donald W. Kerst, of the University of Illinois, who came to the General Electric Laboratory for a year and a half to work on the device. The 20,000,000-volt equipment, after it was used for preliminary experiments at Schenectady, is now at the University of Illinois, while the G. E. scientists are completing a still larger one, capable of speeding electrons to 100,000,000 volts.

The operation of this device is suggestive of the cyclotron, for it also speeds its atomic bullets in a spiral path between the poles of a powerful magnet. However, where the cyclotron uses positive particles, the accelerator works on negatively-charged electrons. They start from a hot filament, inside a doughnut-shaped vacuum tube, and magnetic forces from the alternating-current electromagnet whirl them around. It accelerates them steadily instead of in jumps across a gap, as in the cyclotron. The forces involved are really similar to those in a transformer, where there are two coils of wire around an iron core. When alternating current passes through one, the primary, an "induced" current is made to pass through the other, called the "secondary."

An electric current in a wire is a flow of electrons, so in the secondary of a transformer there is such a stream. In the accelerator these electrons flow not along wires but in the open space inside the vacuum tube, until they have nearly the speed of light. Then they can be made to fall on a metal target—and there are X-rays of the same high voltage, greater than any hitherto created. But the electrons themselves can also be brought outside the tube and used, for example, to bombard atomic nuclei. They offer great possibilities for biological work as well, since they may be sent right into the body. No one yet knows what their results will be; but the electron accelerator offers every possibility of being one of the powerful new tools of science in the future, for it permits experiments with the high-velocity electrons to keep pace with those of the positive particles from the cyclotron. We will be hearing more about the electron accelerator in years to come.

XX. *New Sources of Power*

Our civilization is based on power; not the power of a despotic group to bend other men to their will, but the power that drives the machines in our factories, that drives our trains across the country, our ships over the waves and our airplanes through the sky. From 1920 to 1940 the total production of electrical energy in the United States rose from 43 billion to 145 billion kilowatt hours. Yet even this is not enough, and the output is being increased at a greatly accelerated rate. This augmented power will come, as does all our power, from the sun—some, perhaps, in a direct conversion of solar radiation into electricity, the rest by the indirect means we now use. Perhaps it is not at once obvious that this statement is true. However, a little consideration reveals that it is.

Water power? Surely this comes from the sun, whose rays warm the waters of the ocean and lakes, evaporating them so they are carried through the air and fall on high ground as rain. In returning to the ocean they may operate turbines and drive generators on the way.

“How about windmills?” one might inquire. Yes, here too the sun is the source, for its warming rays produce the areas of different temperature and pressure in the atmosphere that make the winds blow from one place to another.

Similar is the case of boilers fired by coal or oil. These fuels are the remains of vegetation of past geologic ages, which grew and acquired energy through their leaves from the sun in the process of photosynthesis. The same thing, of course, is true of the gasoline burned in internal combustion engines.

Also there is tidal power. The moon, as well as the sun, is responsible for the tides; but many astronomers think that the moon was originally a part of the earth which was pulled out

of our globe by earlier tidal forces, originating with the sun. While, at the present time, there is no entirely satisfactory theory to explain the origin of the earth and the other planets, it may well be that our globe was originally part of the sun; and in that event, even if power from atomic sources is someday achieved, that also would have a solar origin.

At the present time, we are still mainly dependent upon indirect connection with the sun, and are following the path pioneered about two centuries ago by Newcomen and by Watt. Steam is an important step in the process; from the earlier reciprocating engines in which steam was admitted to a cylinder to push on a piston, and was then exhausted as the piston returned to prepare for another push, we have the highly efficient steam turbine. In the turbine the push is continuous, like a steady wind spinning the blades of a windmill, but many refinements have been made to get the greatest possible amount of energy out of the steam. Water boils at 100° Centigrade (or 212° Fahrenheit) and that is the temperature of the steam in an ordinary teakettle. If the temperature is lowered beneath that figure, at ordinary pressure it condenses back to water; but the steam can be further heated and more and more energy put into it.

To get this energy out in the form of motion of a shaft, it is not sufficient merely to squirt the jet of steam against windmill blades. The modern turbine, which traces its invention back half a century to Sir Charles Parsons, uses the same steam over and over again, driving a whole series of windmills. Heated to nearly 1000° Fahrenheit, it is driven through carefully designed nozzles and against curved blades in the rotor which are designed with equal care. These blades are curved, and themselves act as jets to shoot the steam back again. This gives a reaction, like the kick of a gun or the expanding gases of a skyrocket, and adds more drive to the spinning wheel. But still the steam has not done all its work. It passes through a series of stationary blades, curved in the opposite direction from those of the rotor, and emerges to strike against still another spinning

set—and the same process takes place again. This may be repeated a dozen times. At each stage the steam, originally highly compressed, expands as it gives up energy, so each rotor is larger than the one before. The steam, at the end, emerges at atmospheric pressure and about as hot as boiling water.

Ten years ago temperatures of about 750° Fahrenheit were the highest that could be used commercially, for, even though engineers realized that higher temperatures would mean higher efficiencies, the turbine blades would not survive. The heating produced molecular changes, and they would easily break with the high centrifugal forces to which they were subjected. Now new alloys have been developed that retain their strength up to 1000° Fahrenheit, where they begin to become red hot, and these have been used in one of the newest installations. This is the General Electric turbine generator which was recently installed in the Twin Branch station of the Indiana and Michigan Electric Co., which is located near South Bend, Indiana.

Steam is fed into the high-pressure unit at 940° Fahrenheit and a pressure of 2300 pounds per square inch, which is the highest ever used in an electric-utility generating station in the United States. The rotors spin at 3600 revolutions per minute. The previous record for steam pressure—1400 pounds—was held by two G-E machines, installed by the Pacific Gas and Electric Company less than a year before. The chief engineer of the Indiana company, Philip Sporn, has reported that the new high-pressure unit consumes just a pound of Indiana coal to give one kilowatt-hour of electrical energy. The average turbine, as used today, requires two-thirds more heat for the same output. After the steam emerges from the unit, it is reheated to 900° Fahrenheit, then fed into a low-pressure turbine which revolves at 1800 rpm, thus making use of the energy that remains.

The possibility of further increase is indicated by tests that have been conducted on new alloys that retain their strength up to 1100° Fahrenheit. These contain iron; but they are not classed as steel, because they contain no carbon.

In general, a thermodynamic cycle such as that involved in heating water, making steam, running an engine and condensing the exhaust steam to water again, is more efficient the greater the range of temperature through which it operates. But there are practical limits to the efficiency that can be obtained by heating the steam above the boiling point. This difficulty can be overcome by using a binary cycle; that is, by employing two different vapors, one of which has a much higher boiling point than the other. Of all other vapors besides water, mercury, which boils at 675° Fahrenheit, has proven best.¹

Today's mercury boiler unit has an oil-fired boiler which vaporizes the mercury. The vapor drives a turbine, then is condensed back to a liquid again as it passes next to pipes through which water is flowing. The heat, which is thus transferred to the water, changes it to steam, and this in turn is superheated by the exhaust gases from the mercury boiler. This then drives a series of steam turbines of the usual type.

One of the problems which seriously hampered the use of binary cycles by large plants was the attack of the mercury on the steel tubes of the boiler, and the formation of lumps of an iron crystalline deposit which plugged the tubes. After extensive research it was found that by dissolving small amounts of magnesium and titanium in the mercury, and by keeping all oxygen out of the system, this difficulty could be eliminated. Two of the largest commercial units have been redesigned to take full advantage of this improvement. One of them (that at Schenectady) now produces a kilowatt hour for each half-pound of fuel oil that is burned—which is a new record, and is about ten per cent better than the most efficient all-steam plants. In the other (at Kearny, N.J.) 21,000 kilowatts are produced by the mercury and 30,000 from the steam. Engineers

¹ In 1913 the first experimental model of a mercury boiler for power was made by a General Electric engineer, Dr. William LeRoy Emmet. Studies with this led to the first commercial unit ten years later, built for the Hartford Electric Light Company, to deliver 1800 kilowatts. Later a larger one, of 10,000 kw, was made for the same company; then, in 1932 and 1933, 20,000 kw plants for the G. E. Schenectady works, and for the Kearny station of the Public Service Electric and Gas Company of New Jersey.

predict that with the data now secured it would be possible in a new plant to produce a kilowatt-hour of electrical power with 0.41 pounds of fuel oil.

As a foretaste of what the future may bring there is also the gas turbine, in which the vapor stage (whether of mercury or steam) is eliminated and a stream of hot gases drives the turbine blades directly. A pioneer experimenter with this is Dr. Sanford A. Moss, whose turbosupercharger for airplanes has already been described. The motive power of the supercharger comes from a gas turbine, driven by exhaust gases from the engine.

The gas turbine is used on the ground as well. It has been employed in oil refineries, for instance, where there is a copious supply of hot gases, formerly wasted. Thus its main application has been to produce useful power as a by-product. Perhaps some day, however, oil or coal will be burned not to make steam but to produce hot gases to give the turbine blades their push, and the energy wasted in the intermediate vapor stage will be saved. But there are still many problems to be solved before this can be accomplished.

Such developments as the mercury boiler have come because engineers do not like to see power, or anything else, wasted, and they have looked longingly at the many places in nature where power is consumed without doing useful work. The falling of water over Niagara Falls is an example. Probably few, even among engineers, would deny the aesthetic value of those falls or urge their complete abolition and dedication to power production—the fate which other falls, like those at Trollhättan, in Sweden, have suffered. But without disturbing the beauty of Niagara, large amounts of power to drive important war production both in the United States and Canada have been generated from water that is diverted from the falls to drive hydraulic turbines as it drops to the level of Lake Ontario.

Less steady than the falling of water is the movement of the atmosphere in wind. The windmills used on American farms for raising water can operate only occasionally and still keep storage tanks filled; but if the windmill is to be a useful source of power for industry, it must be more regular. To help attain this end, it can be installed in a place where winds blow a large proportion of the time. Such an experiment is being carried out on top of a 2000-foot summit, called Grandpa's Knob, in Vermont. Designed to give 1000 kw (more than 1300 horsepower) it has two enormous blades. Sixteen feet in maximum width, they are as big as the wings of a bombing plane—and about the same shape, too, for they have been designed in strict accord with aerodynamic principles. They weigh seventy-five tons, and, mounted at the top of a 100-foot tower, they sweep about a circle 175 feet in diameter.

It is estimated that the installation on Grandpa's Knob will produce current about half the time through the year. This will feed into the lines of the Central Vermont Public Service Company. To keep the output uniform while the windmill is running, it is designed so that it maintains a speed of thirty revolutions per minute whether there is a gale of seventy miles per hour or a breeze of fifteen miles per hour. This is accomplished by automatic feathering; that is, the pitch, or the angle which the blades present to the oncoming wind, is changed with the alterations in wind velocity. Although it takes a short time for the blades to shift after the wind changes, they are so massive that they act as a flywheel; inertia keeps them turning at a constant rate.

The generator will not be a primary supply for the Central Vermont Company, but rather an auxiliary source, supplementing others already in use. Much of the company's energy is now obtained from water power, and the water, impounded behind dams, can be used when the wind is not blowing. Conversely, when the wind generator is running some of the water can be saved. Since wind studies on other Vermont peaks have already been started, it has been suggested that, if the Grandpa's Knob

installation is the success that its designers hope it to be, New England's mountains may eventually have as many windmills as Holland.

Power from the ocean is another possibility that has engaged the attention of many scientists. A few years ago the world was interested in the experiments in the West Indies of the French physicist, Georges Claude. It is possible to run a heat engine, analogous to a steam engine, with relatively small temperature differences. Even though the efficiency is not high, if you can get large quantities of warm and cool water without cost you may be able to produce power economically. So Claude made use of the difference in temperature between the warm water at the surface of the Caribbean Sea and the cooler water from the depths. He was actually able to get power, but the trouble was that it took more power than he obtained to pump up the cooler liquid, so the process was hardly a feasible one.

Waves too are thought of as a power source, but no satisfactory means of utilizing them has ever been devised. The movement of the tide seems somewhat more likely to give success, though the one-time plans for a great tidal power project at Passamaquoddy, Maine, have been laid to rest with little regret by engineers. Here the idea was to dam up two bays, making natural reservoirs. By keeping them at different levels and alternating between the two the direction of the water flow, it would be possible to keep the power output constant, regardless of the variation in the heights and times of the tides. But other factors made the plan seem uneconomical. For one thing, the corrosion of the pipes and turbines by the sea water would be an expensive item. And there was still the need of distributing the current generated, which often is considerably more expensive than the cost of producing it, even from coal or oil.

Since all our energy comes from the sun, why not utilize the sun's rays directly? This is a question many have asked and have

tried to answer; and several important researches aiming to answer it are now in progress. There is certainly plenty of energy there, for, in our latitudes, every square foot of ground on which the sun shines receives about a tenth of a horsepower. The average family could operate all its lights and electrical appliances from the energy falling on a square yard of the roof. A factory could run its machinery with the energy its roof receives—provided it could all be utilized.

The photovoltaic cell (it was described on page 178) converts light directly into electricity, but the efficiency is very low and the cells are fairly expensive to construct. Research, however, may improve both these factors. Then our deserts may be covered with photovoltaic cells—but once more, of course, comes the expense of transmission. Using the factory roof as a power source might eliminate this, for the output would then be consumed close to the point of generation.

For many years Dr. Charles G. Abbot, secretary of the Smithsonian Institution, has been carrying on experiments using solar energy in a different way. It is the heat rather than the light that he employs. The most satisfactory results have been obtained by employing a long sheet of polished metal bent to the shape of a parabola, so that the solar rays are focused along a line down the middle of the reflector. At this position is a pipe, blackened on the outside to make it absorb all possible heat, which acts as a boiler. It is a boiler of the "flash" type—that is, it is kept hot, and water is admitted a little bit at a time, so that it immediately vaporizes. The steam can then be used to run a small engine. Of course the sun moves across the sky, so it is necessary to move the reflector. Dr. Abbot arranged the device on a slant, with the boiler parallel to the axis of the earth; the reflector, driven by clockwork to keep it aimed sunwards, turns once a day around the boiler as a center. Some experts have expressed doubt whether the efficiency of fifteen per cent of such a plant in producing electrical energy, which Dr. Abbot has attained, can ever be much exceeded.

However, when it comes to heating rather than power production, this method seems more likely to succeed. For many years, at an observing station maintained by the Smithsonian Institution at Mt. Wilson in California, Dr. Abbot had in operation a solar cooker. As in the power plant, a long parabolic reflector gathered the sun's heat rays and focused them on a pipe. This was not a boiler; through it circulated oil which, when heated, traveled up to an oven, which it maintained at a high-enough temperature to cook with. After the oil had given up its heat, it moved down to the bottom of the heater again. By having a large insulated storage tank for the hot oil, Dr. Abbot was able to keep the oven hot during the night, and cooking could be done at any time.

An extensive program of research on utilizing solar energy has been inaugurated at the Massachusetts Institute of Technology at Cambridge, and an experimental house has been built there to test the practicability of heating, and even cooling, houses with the sun's rays. It may seem contradictory that a house could be cooled with heat, but both cooling and heating are essentially the same. Both are the transfer of heat from one place to another. In the mechanical refrigerator, you take heat from inside the box and dissipate it outside. In the type with water connections, the heat warms the water, which then drains away; while in the independent type, which just requires plugging into an electrical outlet, the heat raises the room temperature as the refrigerator temperature goes down. When a theater or restaurant is air conditioned in summer, the inside of the theater is cooled but the out-of-doors is warmed. An air-conditioning system can be used, with very little change, to warm a building in cold weather. Then the heat from the outside (which is thus made still cooler) is carried inside—simply the summer process in reverse.

To make such a transfer of heat requires energy, and in the electric refrigerator this is supplied by the electrical current. But in one non-electrical type, the Electrolux, a gas flame sup-

plies the energy. Where there is no gas supply a kerosene flame works as well; only a slight modification would be needed to use solar heat instead of a flame.

Following is an extract from a statement issued by M.I.T. in announcing one of several projects planned under the solar-energy program made possible by a gift, in 1938 from the Cabot Fund, of \$650,000 for research on the utilization of solar radiation for the tasks of man. (These projects are carried on under the direction of Prof. Hoyt C. Hottel, of the department of chemical engineering.) Says the Institute:

The purpose of the investigation is to study various uses for solar heat, including winter house heating, summer air conditioning and power generation. In the basement of the specially designed laboratory house is a large well-insulated water storage tank which will be used for ironing out the fluctuations in a source so variable as the sun. The building's heating system consists of a method of forced air circulation so arranged that the flow of air can be either over the hot tank surface, or through the coils of the refrigeration system to be installed later. The refrigeration system, operating on an absorption principle, will utilize sunlight as its heat source.

While the Technology engineers are well aware that the amount of solar heat in New England would make domestic heating by solar radiation uneconomical in comparison with other sources of heat, there is sufficient sunshine in this region to test the efficiency of heating systems for localities where the climate is less rigorous.

Professor Hottel explained that, although several types of energy collectors, or "heat traps," are to be tried in the Technology research program, first attention is to be given to a shallow, box-like heat collecting device placed in a recess on the roof of the building. The bottom of the box is a thin sheet of metal painted black to absorb the utmost amount of solar energy. Firmly fixed to the under side of the sheet is a series of small thin-walled metal tubes which are heated by contact with the sheet and which in turn heat water circulated through them.

The box has several covers of glass, interspersed with dead air regions, through which nearly all the sunlight can pass, but back through which little heat can escape. The sunlight is converted into heat when it strikes the metal sheet. Beneath the box is a layer of mineral wool to prevent the escape of heat in that direction.

After the water has been warmed in the heat collector, it passes

through carefully insulated pipes to the storage tank in the basement. The tank is so thoroughly insulated that it will lose little heat over long periods of time. Depending on the size of the tank, water can be kept hot from a few weeks to a half year by this method. To use the heat in the storage tank for heating purposes, a system of forced air circulation is employed in which the air passes through ducts, one wall of which is the hot side of the tank.

Several methods of operating such a solar heating system are to be studied at the Institute. A sunlight collector large enough to heat the house directly might be used, thus making necessary only a small storage tank to heat the house during periods of a few weeks when the weather was cloudy. Or a small collector might be used, and heat stored all summer in a tank large enough to hoard an entire winter's supply of heat.

Part of the research at the Institute will be to study these methods of operation and also to study the most efficient types of paint to use on the collecting devices, the most effective number of glass plates to use over the collector, and the best angle of roof slope to meet the requirements of various types of heaters. The roof on the Institute's sun laboratory slants at an angle of 30 degrees with the ground. The greater the number of glass plates used, the greater the insulation against heat loss, but each additional plate cuts down by about eight per cent the amount of sunlight which may pass through to the absorbing sheet.

On the Institute's agenda are several other solar energy researches. One is on the use of photoelectric cells; another will employ the thermoelectric effect. Suppose you take two copper wires running from a galvanometer (which is merely a very sensitive electric-current meter) and join an iron wire between their ends so that there are two iron-copper junctions. This is called a thermocouple. If one of these junctions is put in hot water, the other in ice water, a current will flow and will be indicated by the galvanometer. The same thing will happen when one of the junctions is left in the air, at room temperature, and the other is heated in a gas flame. Or the thermocouple could also be heated with the sun's rays, focused by a lens; and then you would have the solar radiation converted into elec-

tricity. Professor Hottel has discussed this in an article in which he said:²

The phenomenon involved here has itself long been known; many investigators have been led to speculate upon it as a possibility for large-scale thermoelectric power production, but then to dismiss it as unimportant because the effect is so small. The recent discovery, however, of several alloys or compounds having the desired combination of low electrical resistance, low heat conductivity and high thermoelectric effect has made it distinctly interesting from an engineering as well as a scientific point of view.

Such compounds as lead sulfide with bismuth sulfide, or bismuth and antimony sulfides, prepared by the methods of powder metallurgy, have proved quite promising. With them an efficiency of five per cent has been achieved in converting thermal to electrical energy, with heat available at 450° Centigrade and thrown away at 25° Centigrade. Of course, the development of highly efficient thermocouples affords many opportunities other than those involving solar power. They offer the hope (a most distant one, to be sure) that some day boilers, steam engines and electrical generators will no longer be a stage in converting the heat of coal or oil into electricity. Instead, the flames may heat thermocouples, and current will flow without the wastefulness of the intermediate steps.

Or, as Professor Hottel has pointed out, the process may be used the other way—for cooling. When current is made to flow through a thermocouple, a difference of temperature is produced between the two junctions. If the warm junction is at room temperature, there is thus a refrigerating effect. He has found it possible to produce temperature differences as great as 40° Centigrade by this means, and he foresees the possibility of cooling with heat in a very simple way: that is, “generate electricity thermoelectrically by use of a high and intermediate temperature, then use that energy in a second thermoelectric unit to obtain a low and an intermediate temperature and thus obtain a heat-operated refrigerator.”

² *The Technology Review*, Vol. 42 (March 1940), p. 195.

The principal uncertainty in such speculations is that science still has very slight knowledge of what happens when electricity is generated at a thermocouple. Theoretical researches into this are going on, and as a result it may be possible to predict whether it is likely that alloys may be discovered to make feasible such a process of power production, or whether there is some insurmountable barrier to its attainment.

What seems to be the best approach to using solar energy—and this forms one of the main parts of the M.I.T. program—is by imitating, or perhaps surpassing, the process by which nature uses it in living plants. Chlorophyll, the green coloring matter, absorbs light energy and uses it to convert carbon dioxide and water into carbohydrates, which in turn are used for food to keep animals alive. This is the most important of all chemical processes, but its details are not understood.

In speaking to the American Chemical Society on the subject, Professor C. C. Furnas, of Yale University's Sterling Chemistry Laboratory, said that the basis of this process seems to be some simple photochemical reaction such as one in which water and carbon dioxide and radiant energy react to form formaldehyde and oxygen. He continued:

The formaldehyde immediately forms simple sugars which then serve as the basic material for the multitude of complex compounds in plants. What we should like to do would be to take some such simple compound as formaldehyde formed with the help of radiant energy, put it into an electro-chemical cell, expose it to oxygen, and then reverse the above reaction and get back the stored energy as electrical energy—at high efficiency. Formaldehyde can be oxidized in a cell in a basic solution to give formic acid and a small amount of electrical energy. Perhaps all that is needed is a proper catalyst to complete the oxidation to carbon dioxide and water and get back all the stored energy.

The catalyst which nature uses for performing the photosynthesis is chlorophyll. That's the best catalyst known, but it is very poor. Plants are very inefficient stores of energy. Even the most luxuriant plants have an energy storage efficiency of less than two per cent. We ought to be able to do a lot better than that.

It is a wide open field, this study of photosynthesis and the study

of oxidation cells which will reverse the reaction. That is the reason it is hopeful. The systems which might be used would not have to be limited to organic compounds. It may well be that inorganic compounds offer the most hope. The satisfactory system would be one that is as light sensitive as the chemicals on a photographic film, as easily reversible as a lead storage cell. The storage of the energy would be simply that of storing chemical compounds. We are used to doing that with coal.

A possible clue has been found by one of the Cabot Fund researchers, Dr. Eugene Rabinowitch, who is seeking organic dyes that might perform a function similar to that of chlorophyll in plants. A purple dye called thionine, and methylene blue, are two that work. There are two iron sulfates, the ferrous and the ferric forms. The former consists of an iron atom linked with a sulfate "radical" which is made of a sulfur atom with four oxygens. Ferric sulfate has two iron atoms with three sulfates. Under the influence of light and one of the dyes, ferrous sulfate is changed into ferric sulfate.

Since the iron atom has a positive charge and the sulfate ion (as the sulfate radical is called when it breaks off in solution) is negative, there is an excess of negative charge in ferric sulfate, while it equals the positive charge on the iron ion in the ferrous sulfate. Immersing two metal electrodes into a ferric sulfate solution, and exposing one to light while the other is kept in the dark, makes an electric cell which yields a small current as long as the illumination continues, found Dr. Rabinowitch. The ferric salt forms around the electrode on which the light shines, and reverts to the ferrous sulfate around the dark electrode. If the two electrodes are connected by a wire, electrons flow—in other words, there is an electrical current.

According to reports of Dr. Rabinowitch's work, the efficiency of such a light cell is very low, about a tenth as much as that of chlorophyll—which itself is quite inefficient, since it uses only about one per cent of the light energy that falls upon the leaf. But at least this research may point the way; now that science has some idea of what to look for, more efficient con-

verters than the thionine and methylene blue may be discovered.

Whether we succeed, by methods such as these, in getting energy more directly from the sun, or whether we use it in the form of coal, oil or water power, there is still a lot of power lost between the sun and us. At the solar surface every square inch is sending out some sixty horsepower. It is broadcast freely in all directions, and only $\frac{1}{2},000,000,000$ is intercepted by our planet. By far the greater part of the sun's output is distributed promiscuously out into space.

Carrying the problem back a stage, we might well ask how the sun itself keeps going. Only in the last few years have astronomers found what seems to be a satisfactory answer—one given by the studies of Dr. Hans Bethe, of Cornell University. The sun is really an enormous atom-smasher. With temperatures at its heart of around $20,000,000^{\circ}$ Centigrade and pressures about $15,000,000,000$ pounds per square inch, strange things happen—things which we can hardly hope to imitate.

According to the modern conception, there are six stages in the atom-smashing process of the sun. Hydrogen is the fuel, helium is the ash. Carbon is the catalyst which makes the process possible; during the series it changes to nitrogen, then returns to carbon at the end. Some of the steps occur in a few minutes, others in thousands or millions of years. It would take several million years, on the average, for any one carbon atom to yield a helium atom.

Fortunately, there happen to be such a vast number of atoms in the center of the sun that the production of other atoms, along with energy, proceeds at enormous intensity. It all takes place in the nuclei of the atoms, from which the outer electrons have been completely stripped off. Starting with a nucleus of the most common kind of carbon, of mass 12, a hydrogen nucleus (a proton) comes along, unites with it to form nitrogen

of mass thirteen. Energy, in the form of a gamma ray, is given off. But nitrogen 13 is unstable; in ten minutes it gives off a positive electron and turns into carbon of mass 13, an isotope which makes up a little less than one per cent of ordinary carbon. A positive electron comes off. Then, 50,000 years later, another proton happens by, unites with the carbon 13, transmutes it into nitrogen 14, the kind that makes up nearly one hundred per cent of nitrogen in the air. Again energy is radiated, as another gamma ray.

The nitrogen 14 has quite a respectable life of 4,000,000 years before it changes. When it does, a proton is again the agent. It turns into oxygen 15, and another gamma ray is emitted. But oxygen 15 is unstable; only two minutes are required for it spontaneously to decompose into nitrogen 15 (the isotope which makes up about 0.14 per cent of the ordinary gas), and to give up another positive electron. After twenty years the nitrogen 15 changes, with the aid of a fourth hydrogen nucleus, into carbon 12—and helium. The latter is not changed, but the carbon is ready, after 2,500,000 years, to join with a proton in starting the cycle all over again.

The sun's fuel is hydrogen, which is used up, and it contains enough to keep it going for many billions of years to come. Perhaps, also, it picks up hydrogen in its journey through space; and if so, the sun's life may be even longer.

Although there is no hope of duplicating such a process as this on earth, within the last few years it has begun to appear that a form of atomic energy may eventually be made available by man. Before 1939 all known nuclear reactions produced relatively small amounts of energy, considerably less than that required to produce the atomic bullets to instigate the reaction. Then experiments in Europe, soon confirmed in the United States, revealed that neutrons, moving slowly and with little energy, are able to make nuclei of uranium, the heaviest element, divide into two parts; two other nuclei of, for example, krypton and barium, elements of medium weight. But most sig-

nificant is that in the process more neutrons are emitted, along with a large amount of energy.

Physicists realized immediately the exciting possibility which this heralded. For if the neutrons given off could be used to break more uranium nuclei, a chain process could be started which would keep on going by itself. Since fast neutrons have no effect, because they go right on through the atomic nuclei, those coming from the dividing process would have to be slowed. But this could be done by immersing the uranium in water. Then the water would absorb the energy given off, and the steam generated could be used to provide power. To stop the process all that would be needed, apparently, would be to lift the uranium out of the water.

Ordinary uranium will not act in this way, so scientists suspected that only one of the three isotopes of which it is made will show the effect—the others inhibiting it in some way. In the spring of 1940 Dr. Alfred O. Nier, at the University of Minnesota, and Drs. K. H. Kingdon and H. C. Pollock, at the General Electric Research Laboratory, succeeded in separating minute quantities of the uranium isotopes. They used mass spectrometers. Starting with uranium tetrachloride, they vaporized it in a tiny oven, let it emerge through a tiny slit. There the vapor was bombarded by electrons to make uranium ions out of it. With the whole apparatus placed in a powerful magnetic field, the ions curved around as they were accelerated by an electric field. Since the lighter ion paths curved most, the different isotopes were thus sorted out and collected on platinum plates at the end of a copper tube.

Ordinary uranium consists mostly of an isotope of mass 238; that is, 238 times as much as hydrogen. About one part in 140 is an isotope of mass 235 and one part in 17,000 of mass 234. Though almost infinitesimal amounts of the pure isotopes 235 and 238 were isolated by the experimenters in Minneapolis and Schenectady, these were enough to test. The samples were sent to Dr. J. R. Dunning, of Columbia University, who fired

slow neutrons from the cyclotron at them. The amounts obtained were not enough to make a test of the chain-reaction process; but it was determined that uranium 235 was the one which divided under the bombardment.

Since then, the problem has been to isolate enough U235 to make a real test. It is known that intensive research has been carried on since the first announcements in 1940, but with results not revealed; the initial steps of the experiment were necessarily undertaken in wartime secrecy. One can only infer that the mass spectrometer is not being heavily relied on, for, at its former rate of production, to extract a pound of the stuff by that means would take 12,000,000 years! If U235 will behave in the way expected, manifesting the chain reaction . . . but that remains one of the big "ifs" of science, which has encountered so many "ifs" and turned them to advantage. Meantime, however, the following words of Dr. Kingdon, written in 1940, are still to be heeded:

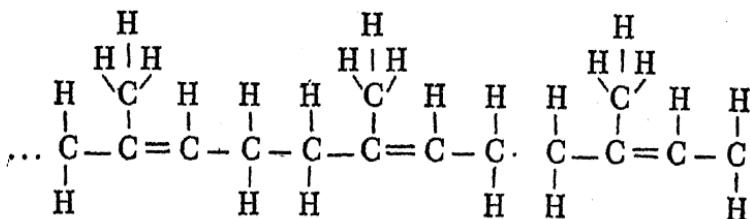
"While it seems unlikely that this energy source will displace our present means of getting power, it cannot be denied that such a source should have important implications, as it is estimated that several million times as much power could be obtained from U235 as from an equal weight of coal. These applications will involve problems of proper control of the power, and protection against the tremendous neutron and X-ray radiations which will accompany it. It may be that the use of these radiations in therapy will be one of the most important applications. But detailed discussion of these questions is premature until further progress has been made. . . ."

Appendix

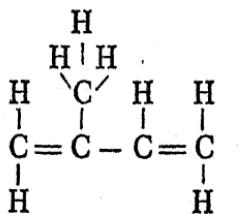
RUBBER AND ITS RELATIVES

—See Text, Page 67—

Natural rubber is made of long molecules like this (each C represents a carbon atom and each H a hydrogen atom):

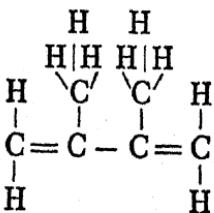


This is really a repetition of a single link, or "monomer,"



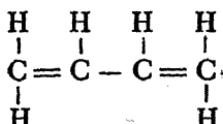
called ISOPRENE.

The arrangement is called a "methyl" group, and another can be attached in place of the other H in the middle, thus:



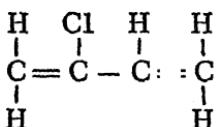
and this is called
DIMETHYLBUTADIENE.

When this monomer is linked together, we have a chain molecule, or "polymer," which is *methyl rubber*, used by the Germans during World War I. But both isoprene and dimethylbutadiene are really modifications of a simpler monomer, with an H in place of each methyl group:



which is called BUTADIENE.

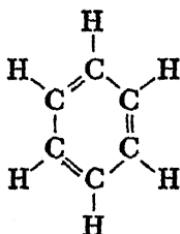
Linking together, or "polymerizing," this unit gives us a synthetic rubber which has been used in Russia and also, formerly, in Germany, under the name of *Buna 85* and *Buna 115*. However, one of the middle Hs in butadiene can be replaced by an atom of chlorine (Cl):



called CHLOROPRENE.

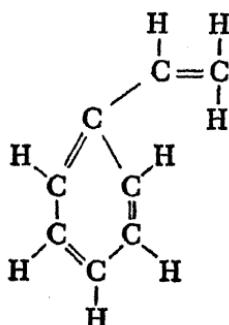
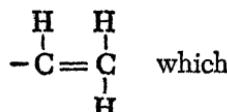
The polymer of this was the first successful American synthetic rubber, *Neoprene*, and it has also been made in Russia under the name of *Sovprene*.

Six carbons and six hydrogens may be linked together in a ring:



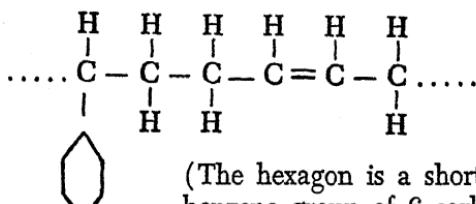
which is BENZENE,

and when this is attached to a vinyl group: it is really half of a butadiene monomer, like this:



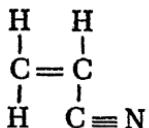
we have vinylbenzene, or STYRENE.

Now we can make a chain with alternate links (called a "co-polymer") of styrene and butadiene, in which the units are like this:



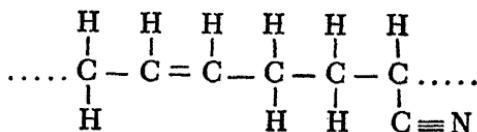
(The hexagon is a short way of indicating the benzene group of 6 carbons and the connected hydrogens.)

This is a synthetic rubber widely used in Germany as *Buna S*; and its manufacture in the U.S. has begun. Or instead of styrene, we can take another group, in which carbon and nitrogen CN take the place of the benzene ring:



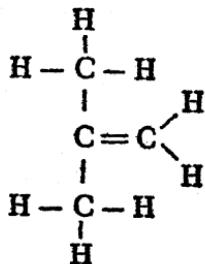
which is vinyl cyanide, or
ACRYLONITRILE

and alternating this with butadiene we have the unit:



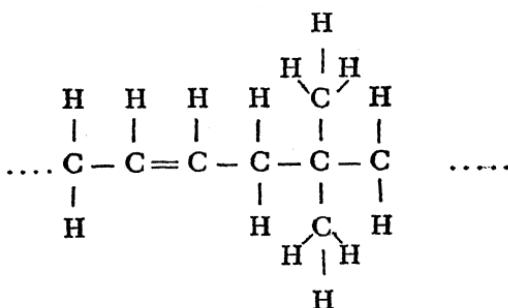
made in Germany as *Buna N* and in the United States as *Perbunan*, *Chemigum*, *Ameripol* and *Hycar*.

A third co-polymer may be made with a group of 4 carbons and 8 hydrogens; including two methyl groups:

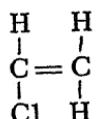


called ISOBUTYLENE,

which, when alternated with butadiene, is:



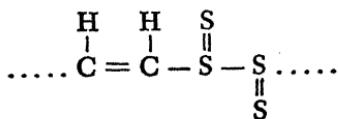
and this is reported to be the structure of *Butyl Rubber*. Also, isobutylene itself may be polymerized; and this has been prepared under the name of *Vistanex*. Unlike most synthetic rubbers on the market, butadiene is absent in *Vistanex*. Using the vinyl group attached to chlorine.



which is VINYL CHLORIDE.

we can make up a polymer which is sold as *Flamenol* and also as *Koro seal*.

Another synthetic rubber is called *Thiokol*, and is distinguished by the presence of sulfur. In one form the units of the polymer are:



Index

Abbé, Ernst, 149
Abbot, Charles G., 274
Accelerator, induction electron, 265
Acetone, 76
Achromatic lens, 148
Acid, ascorbic, 105
 nicotinic, 104
 oxalic, 80
 pantothenic, 95
 para-aminobenzoic, 109
 picric, 16
 sulfuric, 8
 thioglycollic, 57
Acrylic resins, 43
Acrylonitrile, 287
Adaptability of eye, 210
Additive color mixture, 229
Aerial color photography, 234
Agfacolor, 233
Air Corps, U.S.A., 234
Airgraph, 238
Airplane detection, 166
Airplanes, plastic, 42
Alchemists, 11
Alchemy, 255
Alcohol, 36
 methyl, 77
Alexanderson, E. F. W., 194, 201
Alkyd resins, 45
Alkylation, 57
Allegheny Ludlum Steel Corp., 118,
 127
Alloys, 111
 high temperature, 269
Alnico, 123
Alpha particles, 257
Alpha-tocopherol, 101
Alumina, 114
Aluminum, 112
Aluminum Company of America, 115
Alunite, 114
AM, 189
Amatol, 17
Amber, 35
American Chemical Society, 34, 64, 69,
 80, 96-97, 109, 185, 213, 279
American Cyanamid and Chemical
 Corp., 18
American Home Products Corp., 110
American Optical Co., 150
American Physical Society, 262
American Viscose Corp., 51
Ameripol, 66, 287
Amerith, 37
Ameroid, 72
Ammonia process, synthetic, 13
Ammonium picrate, 16
Amplitude modulation, 189
Anaconda Copper Co., 120
Ansbacker, S., 109
Aralac, 50, 73
Armstrong, Edwin H., 188
Ascorbic acid, 105
Asphalt, 25
Atlantic Research Associates, 73
Atlas Powder Co., 18
Atom, 4, 255
 structure of, 171
Atomic energy, 282
Atom-smasher, 259
Australian Institute of Automotive En-
 gineers, 31
Autogiro, 157
Bacon, Roger, 15
Bainbridge, Kenneth T., 262
Baird, John L., 195, 201
Bakeland, Leo H., 38
Bakelite, 38
Bakelite Corp., 46
Baking, 10
Bausch and Lomb Optical Co., 150
Bauxite, 112, 114
Beam-splitter, 240
Becket, F. M., 118
Beer, 10

Beetle-ware, 41
 Beggs, E. W., 219
 Bell Telephone Laboratories, 98, 167,
 183, 195, 201, 244
 Benalite, 78
 Benzene, 46, 286
 Bergius, Friedrich, 27
 Bergius process, 8
 Beriberi, 92, 97
 Berl, Ernst, 34, 83
 Bernoulli, Daniel, 156
 Beta rays, 264
 Bethe, Hans, 281
 Biotin, 95
 Birkeland, Kristian, 13
 Bitumen, 35
 "Black light," 120
 Blodgett, Katharine, 152
 Blood-clotting vitamin, 102
 Bohr, Niels, 256
 Bolton, Elmer, 64
 Bomb sight, 151
 Bombs, incendiary, 116
 Booster, 17
 charge, 14
 Bouchardat, Gustave, 63
 Boyd, T. A., 29
 Bragg, Sir William, 180
 Bragg, W. L., 180
 Brass, 112
 Bread, baking, 10
 enriched, 97
 Brearley, Harry, 117
 Brewing, 10
 Brisance, 16
 Broadcasting, 187
 Bromine, 129
 from sea water, 29
 Bronze, 111
 Bronze Age, 112
 Buckley, Oliver E., 206
 Buna rubber, 66, 286
 Bunsen burner, 5
 Burris-Meyer, Harold, 246
 Bursting charge, 14
 Burton, W. M., 25
 Butacite, 44
 Butadiene, 66, 286
 Butanol, 76
 Butter, Karl and Otto, 20
 Butvar, 44
 Butyl rubber, 67, 288
 Cable, coaxial, 204
 gun for cutting, 19
 telephone, 207
 Cadillac, 1912 model, 28
 California Institute of Technology, 152,
 197
 Cambridge University, 170
 Camera, depth of focus, 241
 Electroplane, 241
 Schmidt, 237
 single-shot color, 281
 Candlepower, 210
 Cannon, magnetic, 18
 Caoutchouc, 59
 Carbide and Carbon Chemicals Corp.,
 45, 51, 143
 Carboloy, 119
 Carbon cycle, 282
 Carnegie Corp., 98
 Carnegie Institute of Technology, 34
 Carnegie Institution of Washington,
 149
 Carotenes, 103
 Carothers, Wallace H., 3, 51
 Carpenter, W. S., Jr., 53
 Cartwright, C. Hawley, 152
 Carver, George W., 82
 Casein, 47, 72
 Cast phenolic resins, 40
 Catalysis, 7
 arsenic poisoning in, 9
 in gasoline refining, 38
 Cavendish Laboratory, 170
 Celanese, 37, 49
 Cell, photoelectric, 176
 photovoltaic, 178
 Cellophane, 50
 Cellufoam, 78
 Celluloid, 36, 142
 Celluloid Corporation of America, 37
 Cellulose, 78
 acetate, 37, 49
 coal and oil from, 83
 Central Vermont Public Service Co.,
 272
 Chadwick, James, 258
 Chardonnet, Count Hilaire de, 48
 Charlton, Ernest E., 181
 Chemical Foundation, 118
 Chemical light, 224
 Chemical Warfare Service, 46
 Chemigum, 66, 287

Chemurgy, 70-77
 Chlorophyll, 279
 Chloroprene, 286
 Cholesterol, 108
 Chromium, 117
 Cierva, Juan de la, 157
 Circuit breakers, explosive, 22
 Clarke, Frank Wigglesworth, 183
 Claude, Georges, 273
 Coal oil, 24
 tar, 17
 Cold flame, 6
 Color mixture, additive vs. subtractive, 229
 Color photography, 228
 aerial, 234
 Color-sensitive emulsions, 228
 Columbia University, 98, 102, 115, 134, 188, 258, 265, 283
 Columbus, Christopher, 59
 Combustion, spontaneous, 6
 Commercial Solvents Corp., 76
 Continental Lithographic Corp., 219
 Coolidge, William D., 123, 180, 212, 260
 Copper, 111, 120
 Corning Glass Works, 140, 223
 Cotton, 81
 linters, 82
 Cotton Research Foundation, 81
 Coupling developer, 231
 Cowgill, G. R., 100
 Cracking process, 25
 Crookes, Sir William, 168
 Crown glass, 149
 Crucible Steel Corp., 118
 Cryolite, 114
 Cryptoxanthin, 103
 Crystal detector, 172
 Crystals in textile fibers, 52
 Cullet, 139
 Cuprammonium process, 49
 Curie, Irène, 265
 Curie, Pierre and Marie, 265
 Cyclotron, 260
 dees of, 260
 Daguerre, L. J. M., 226
 Dairy industry, 70
 Dairy Industry, Bureau of, 73
 Davisson, Clinton J., 184
 Day, Arthur L., 150
 De Forest, Lee, 173
 Dentures, magnetic, 126
 Detector, crystal, 172
 Detonator, 14
 Deuterium, 258
 Developer, coupling, 231
 Deville, Henri Sainte-Claire, 118
 Diastase, 10
 Dieterich, L. M., 241
 Diode, 178
 Disney, Walt, 245
 Dispersion, 148
 Diving suits, glass insulation for, 146
 Dollond, John, 148
 Domagk, Gerhard, 86
 Domains, magnetic, 124
 Donath, W. F., 98
 Dorland, Roger M., 78
 Douglas B-19 bomber, 20
 Dow Chemical Co., 46, 116, 130
 Dowmetal, 116, 132
 Dreyfus, Henri and Camille, 49
 Dulux, 45
 Duncan, Robert Kennedy, 2
 Dunning, J. R., 283
 Du Pont Co., 18, 50-51, 68, 106, 143
 Du Pont, Eleuthère Irénée, 18
 Duprene, 64
 Duralumin, 115
 Dynamite, 12
 Eastman, George, 87
 Eastman Kodak Co., 37, 50, 149
 Ebonite, 38
 Eddy currents, 127
 Edgerton, Harold E., 236
 Edison effect, 172
 Edison, Thomas A., 37, 171, 211, 243
 Egloff, Gustav, 81
 Ehrlich, Paul, 86
 "Eighteen-eight," 118
 Eijkman, Christian, 94
 Einstein, Albert, 177
 Ekström, A., 195
 Elastomers, 36
 Electrolux, 275
 Electrolytic Marine Salts Co., 129, 134
 Electron, 171
 accelerator, induction, 265
 gun, 196
 microscope, 184
 multiplier tube, 177

Electron (*Continued*)
 tubes, variety of, 176

Electronic tube, long-lived, 208

Electrons, free, 171

Electroplane camera, 241

Elvehjem, Conrad A., 95-96, 104

Emmet, William Leroy, 270

Enriched flour and bread, 101

Enzymes, 9

Ergosterol, 108

Esters, 36

Ethane, 24, 31

Ethyl-Dow Chemical Co., 130

Ethyl fluid, 129

Ethyl Gasoline Corporation, 129

Ethylene dibromide, 29, 129

Evans, G. M., 88

Explosive D, 16

Explosives, 12
 high, 16
 in oil prospecting, 23
 peacetime uses of, 18

Eyde, Sam, 13

Eye, adaptability of, 210

F value, 237

Fabrics, glass, 146

Factor W, 96

Fantasia, 245

Fantasound, 245

Faraday, Michael, 1, 59

Farbenindustrie, I. G., 27, 63, 86

Farm Chemurgic Council, 70

Federal Communications Commission, 189

Fermi, Enrico, 265

Fiber, casein, 73

Fiberglas, 145

Fink, Colin G., 184

Firefly, light of, 224

Firestone, F. A., 250

Fischer, Rudolph, 231

Flame, cold, 6

Flamenol, 45, 68, 288

Flameware, Pyrex, 140

Flash powder, 235

Fleming, J. A., 173

Flint glass, 149

Flour, whole wheat, 101

Fluorescence, 197, 216

Fluorescent lighting, 218
 in aviation, 220

Flying Fortress, 162

FM, 189

Foamglas, 144

Focal ratio, 200

Focus, depth of, 241

Fog removal, 163

Ford, Henry, 61, 83

Ford Motor Co., 50, 74, 182

Foulger, John H., 107

"Fourth kingdom," 35

Fractionation, 11

Franklin Institute, 143, 156, 233

Freedman, Hyman, 126

Frequency modulation, 189

Frolich, Per K., 67

Funk, Casimir, 94

Furnas, C. C., 279

Gaisford, W. F., 88

Galorn, 72

Gas, marsh, 24
 natural, 25

Gasoline, 17, 25
 carbohydrates as source of, 34
 catalysis in refining, 33
 ethyl, 129
 hundred-octane, 31

Gears, magnetic, 125

Geiger counter, 264

Geissler, Heinrich, 216

General Electric Co., 40, 195, 270

General Electric Research Laboratory, 123, 152, 165, 174, 180, 183, 212, 265, 283

Generator, Van de Graaf, 259

George, Roscoe H., 164

Georgia School of Technology, 83

Germer, L. H., 184

Gladstone, William, 2

Glass, 136-139
 crown, 149
 fabric, 146
 flint, 149
 high-test safety, 143
 insulating, 146
 optical, 147
 Pyrex, 140
 refractive index, 149
 safety, 142
 shrunken, 141
 tempered, 142
 Triplex, 143

Glue, casein, 73
Godowsky, Leopold, Jr., 231
Gold in sea, 129
Goldmark, Peter C., 201
Goldsmith, A. N., 241
Goodrich, B. F., Company, 45, 55, 66
Goodspeed, T. Harper, 61
Goodyear, Charles, 59
Goodyear Tire and Rubber Co., 66
Gordon, N. T., 217
Grandpa's Knob, 272
Grid, in electronic tube, 173
Grijns, Gerritt, 94
Guayule, 62
Guncotton, 15, 36
Gun perforator, 21

Haber, Fritz, 13
Haber process, 8
Half-life of radioactive element, 263
Hall, C. E., 227
Hall, Charles M., 113
Hall, Chester Moor, 148
Hallwachs, W., 176
Hard rubber, 38
Harker, David, 186
Harris, Milton, 57
Hart, Deryl, 222
Hartford Electric Light Co., 270
Harvey, E. Newton, 224
Haskell Laboratory of Industrial Toxicology, 107
Haynes, Ellwood, 119
Heat-prostration and Vitamin C, 105
Heat stroke, 107
Heavy hydrogen, 258
Helicopter, 157
Helium, 22
Hemicelluloses, 79
Henry, Joseph, 1
Heptane, 30
Hercules Powder Co., 18
Héroult, Paul L. T., 118
Herty, Charles H., 80
Hertz, Heinrich, 168, 176
Hertzian waves, 168
Heterodyne circuit, 188
Hevea brasiliensis, 60
Hewitt, Peter Cooper, 216
Hewlett, C. W., 152
Hickman, Kenneth D., 3
High explosives, 16

Hippocrates, 92
Hixson, Arthur W., 115
Homer, Howard J., 153
Honda, 124
Hooke, Robert, 48
Hottel, Hoyt C., 276
Hottest flame, 6
Howe, Goodwin H., 125
Howe, Harrison E., 80
Hull, A. W., 165
Hwangti, 92
Hyatt, John Wesley, 36
Hycar, 66, 287
Hydrocarbon Chemical and Rubber Co., 66
Hydroforming, 33
Hydrogen, 5
 heavy, 258
Hydrogenation, 8, 27
Hydrolysis, 10
Hydroxyl, 36

Illinois, University of, 265
Image, photographic, 227
Incendiary bombs, 116
Indiana and Michigan Electric Co., 269
Indigo, 62
Induction electron accelerator, 265
Infrared light, 163
Inositol, 109
Institute of Aeronautical Sciences, 163
International Rubber Co., 62
Iron, 117
Irradiation of foods, 221
Isobutylene, 287
Iso-octane, 30
Isoprene, 62, 285
Isotopes, 258
Ives, Frederic E., 229, 243
Ives, Herbert E., 243

Jansen, B. C. P., 98
Jena, University of, 149
Jenkins, C. Francis, 37, 195
Joliot, Frederick, 265
Jones, Frank L., 153

KDKA, 187
Kennelly-Heaviside layer, 205
Kenotron, 176
Kerosene, 24

Kerr cell, 199
 Kerst, Donald W., 265
 Kettering, Charles F., 28
 Kinemacolor, 201
 King, Charles G., 105
 King, Edgar L., 85
 Kingdon, K. H., 283
 Klystron, 165
 Knock in automobile engine, 28
 Kodachrome, 231
 Kodacolor, 234
 Kodak, 37
 Kodak Research Laboratory, 227, 231
 Kodapak, 50
 Kodatron speedlamp, 236
 Koroseal, 45, 55, 68, 288
 Krupp Works, 118

 Lamp, carbon-dioxide, 216
 electric, 211
 Mazda, 139
 mercury, 217
 photoflash, 235
 sodium, 223
 tantalum, 212
 tungsten, 212
 Lane-Wells, Inc., 21
 Langley, Samuel P., 155
 Langmuir, Irving, 3, 174, 213
 Lanital, 50, 73
 Large-screen television, 199
 Laue, Max von, 180
 Lavoisier, Antoine Laurent, 6
 Lawrence, Ernest O., 260
 Lead azide, 17
 Lefad, Jim, 121
 Lenard, Philip, 168
 Libby-Owens-Ford Glass Co., 143
 Light, "black," 120
 chemical, 224
 cold, 224
 infrared, 163
 polarized, 242
 Lightning, artificial, 2
 Lignin, 78
 "Lime-juicer," 93
 Linear accelerator, 260
 Long-distance telephony, 203
 Long, Perrin H., 85
 Lucite, 43, 57
 Lumarith, 37
 Lumen, 210

 Lunin, N., 93
 Lustron, 46
 Lyman, Joseph, 168

 Macready, J. A., 162
 Magnesium, 116
 from sea water, 132
 Magnetron, 165
 Magnets, 123-128
 Maltase, 9
 Manganese, 119
 Mannes, Leopold D., 231
 Marconi, Guglielmo, 187
 Martin, Gustav J., 109
 Mason, William H., 77
 Masonite, 77
 Massachusetts Institute of Technology, 152, 236, 275
 Maurer, Eduard, 118
 May and Baker, Ltd., 88
 Mazda lamp, 189
 efficiency of, 215
 McCutcheon, Don M., 182
 Mees, C. E. K., 233
 Mellon Institute, 2, 81, 143, 153
 Merck and Co., 89, 98
 Mercury fulminate, 17
 Mercury-vapor lamp, 216
 Metallurgy, powder, 122
 Meteorites, 112
 Methane, 24, 31
 Methyl rubber, 63, 285
 Metropolitan Opera House, 254
 Microfilm, 238
 Microscope, 147
 electron, 184
 Microwaves, 165
 Midgley, Thomas E., Jr., 29
 Milk, as raw material, 70
 paint from, 72
 Millbank Memorial Fund, 107
 Millers National Federation, 100
 Mine Safety Appliances Co., 19
 Molding powder, 88
 Molecules, large, 39
 water, 5
 Molybdenum, 120
 Monsanto Chemical Co., 46, 143
 Moore, C. N., 152
 Moore, D. McFarlan, 216
 Morey, George W., 149
 Moss, Sanford A., 160, 271

Moth-resistant wool, 58
Motion pictures, sound, 239
stereoscopic, 242
Muscle tone, 107

Napoleon III, 113
National Broadcasting Co., 200
National Bureau of Standards, 57, 115,
181
National Dairy Products Corp., 71
National Research Council, 101
Neoprene, 64, 286
Network television, 203
Newton, Isaac, 148
New York World's Fair, 242
Niacin, 104
Niagara Falls, power from, 271
Nicoll, F. H., 153
Nicotinic acid, 104
Nier, Alfred O., 283
Nieuwland, Julius A., 64
Night vision, 102
Nitration, 36
Nitrocellulose, 15
Nitrogen, atmospheric,
dioxide, 18
in lamps, 214
Nitroglycerine, 15
Nobel, Alfred, 12
Noctovision, 195
Notre Dame, University of, 64
Nuts, chemurgic uses of, 82
Nylon, 3, 54

Oberlin College, 113
Obsidian, 136
Octane number, 30
effect on airplane performance, 32
Oersted, Hans Christian, 113
Oil refining, 26-28
Optical glass, 147
Othmer, Donald F., 80
Overtones, 193
Owens-Corning Fiberglas Corp., 145
Oxalic acid, 80
Oxygen, 5-7

Pacific Gas and Electric Co., 269
Panchromatic emulsions, 228
Panoramic sight, 151
Pantothenic acid, 95
and gray hair, 109

Papain, 10
Para-aminobenzoic acid, 109
Paraffin, 25
Parsons, Sir Charles, 268
Passamaquoddy, 273
Pasteur, Louis, 48
Peanuts, 82
Pearl Harbor, 166
use of sulfa drugs at, 85
Pellagra, 93
Pentane, 24
Perbunan, 66, 287
Perforator for oil well, 21
Periscope, 152
Permalloy, 207
Perminvar, 207
Pettersen, Sverre, 163
Phagocytes, 90
Philadelphia Orchestra, 244
Phosphorescence, 198, 216
Phosphors, 216
Phosphorus, radioactive, 263
Photoelectric cell, 176
Photoelectrons, 177
Photoflash lamp, 235
Photographic image, 227
Photography, 226
color, 228, 234
Photosynthesis, 279
Photovoltaic cell, 178, 274
Picric acid, 16
Pittsburgh Corning Corp., 144
Pittsburgh Plate Glass Co., 143, 150
Pittsburgh, University of, 105
Planck, Max, 177
Plastic airplanes, 42
Plastics, 35
bearings of, 40
formaldehyde in, 38
thermosetting, 35
urea-formaldehyde, 41
vinyl, 56
Platinum, spongy, 9
Play-backs, 239
Plexiglas, 43, 57
Plywood, 41
Pneumonia, 90
Polarized light, 242
Polaroid, 242
Pollock, H. C., 283
Polyamides, 58
Polyhexamethylene adipamide, 58

INDEX

Polymerization, 27
 Polymers, 36
 Polystyrene, 46
 Poulsen, Valdemar, 251
 Powder, black, 15
 flash, 235
 smokeless, 16
 Power, sources of, 267
 sun, 274
 thermocouple, 277
 tides, 273
 wind, 272
 Priestley, Joseph, 6
 Prontosil, 87
 Propane, 24
 Prothrombin, 102
 Protons, 257
 Ptyalin, 9
 Public Service Gas and Electric Co.,
 270
 Purdue University, 164
 Pyralin, 37
 Pyrex glass, 140
 Pyridoxin, 95
 Pyroxylin, 36
 Quartz, 140
 Rabbit brush, 61
 Rabinovitch, Eugene, 280
 Radiation Laboratory, Univ. of Calif.,
 261
 Radio, 187
 links for television, 205
 transmission, 175
 Radioactivity, artificial, 263
 Radio Corporation of America, 153,
 164, 196, 205, 245
 Radiographs, 182
 Ravdin, I. H., 85
 Rayon, 49
 acetate, 37
 Réaumur, R. A., 48
 Recordak, 238
 Refraction, 147
 Regenerative circuit, 188
 Resins, 39
 acrylic, 43
 alkyd, 45
 phenolic, 40
 vinyl, 44
 Research Corp., 247
 Riboflavin, 95, 103
 Rickets, 93
 Riggs, L. K., 71
 Rivets, explosive, 19
 Rockefeller Foundation, 247
 Rockefeller Institute, 109
 Roentgen, Wilhelm Konrad, 168
 Röhm, Otto, 43
 Rosin, 35
 Royal Danish Academy of Sciences,
 118
 Rubber, 59-63
 buna, 66, 286
 butyl, 37, 288
 elasticity of, 63
 guayule, 62
 hard, 38, 67
 methyl, 63, 285
 plantations, 60
 structure of, 285
 Rutherford, Sir Ernest, 256-257
 Safety glass, 142
 Saltpeter, 12
 Saturation, 67
 Scanning disc, 195
 Schaefer, Vincent J., 186
 Scheelite, 120
 Schmidt, Bernard, 200
 Schmidt camera, 237
 Schoen, A. L., 227
 Schott Glass Works, 149
 Schroeder, R. W., 161
 Schwarz, Berthold, 15
 Scurvy, 92
 Sea water, 129
 Sebrell, William H., Jr., 100
 Second Sound Show, 248
 Self-starter, 28
 Semon, Waldo L., 66
 Sextant, 151
 Shapley, Harlow, 237
 Shear disc, 22
 Shellac, 35
 Sherr, Rubby, 262
 Shrunken glass, 141
 Sight, panoramic, 151
 Signal Corps, U. S. Army, 188
 Sikorsky, Igor, 158
 Silk, artificial, 48
 U. S. consumption of, 50
 Silver bromide, 227

Single-shot color camera, 231
Sintering, 122
Slayter, Games, 145
Smith, D. Stanley, 241
Smithsonian Institution, 275
Smokeless powder, 16
Sobrero, Ascanio, 15
Sodium lamp, 223
Solar energy, 281
Sonovox, 249
Sound control, 248
Sovprene, 66, 286
Soy bean, 50, 74
 protein fiber, 75
Space charge, 174
Spectroscope, 147
Spencer Lens Co., 150
Sperry Gyroscope Co., 166
Spies, Tom D., 104
Spirakore transformer, 128
Spontaneous combustion, 6
Sporn, Philip, 269
Standard Oil Co. of Indiana, 25
Standard Oil Co. of New Jersey, 27,
 67
Stanford University, 165
Staphylococcus, 86
Starch, 76
Static, 190
Steel, stainless, 117
Steenbock, Harry, 108, 221
Stellar energy, 282
Stellite, 119
Stereophonic sound transmission, 244
Sterols, 107
Stevens Institute of Technology, 246
Stine, C. M. A., 51
Stockings, runless, 55
Strauss, Benno, 118
Streptococcus, 86
Streptozon, 86
Strong, John, 152
Styrene, 46, 286
Styron, 46
Subtractive color mixture, 229
Sugars, wood, 78
Sulfadiazine, 88
Sulfaguanadine, 88
Sulfanilamide, 86
Sulfapyridine, 88
Sulfathiazole, 88
Sulfuric acid, 8
Sullivan, Eugene C., 154
Superheterodyne circuit, 188
Synthea, 254
Synthesis of natural products, 62
Szent-Györgyi, Albert von, 105
Talbot, William Henry Fox, 226
Tantalum lamp, 212
Taylor, H. D., 152
Technicolor, 240
Telephone, 251
Telephone cable, 207
Telescope, infrared, 164
 200-inch, 179
Television, 194
 color, 201
 large-screen, 199
 network, 203
Tempered glass, 142
"Tenderizing" of meat, 10
Tenite, 87
Terrain distance indicator, 167
Tetraethyl lead, 29
Textile Foundation, 57
Texolite, 40
Thermit, 116
Thermocouple, as power source, 277
Thermoelectric effect, 277
Thermoplastics, 35
Thermosetting plastics, 35
Thiamin, 97, 103
Thioglycolic acid, 57
Thiokol, 288
Thomas, John H., 145
Thomson, G. P., 184
Thomson, Sir J. J., 170, 256
Thunder screen, 252
Thyratron, 176
Tidal power, 267, 273
TNT, 17
Toluene, 33
Tracer elements, 264
Transatlantic telephony, 206
Transformers, 126
Translators, FM, 191
Transmutation, 11
Trinitrotoluene, 17
Triode, 173
Tripack, 231
Triplex glass, 143
Triptane, 31
Trollhättan, 272

Tungsten, 119
 ductile, 213
 lamps, 212
 Turbines, 268, 271
 Turbosupercharger, 160, 271

Ultraviolet irradiation of foods, 221
 United Air Lines, 167
 United States Steel Corp., 118
 Unsaturation, 67
 Uranium, 235, 283
 fission, 282
 Urea-formaldehyde plastics, 41
 Urey, Harold C., 258

Valence, 67
 Van de Graaff generator, 259
 Vanillin, 79
 Varian, Sigurd and Russell, 165
 Vedder, Edward B., 97
 Velocity power tools, 19
 Velox, 38
 Vinylite, 45
 Vinyl plastics, in wearing apparel, 56
 Vinyl resins, 44
 Vinyon, 45, 51
 Viosterol, 108
 Viscose process, 49
 Vistanex, 288
 Vitamin A, 94, 102
 Vitamin B, 94
 Vitamin B₁, 98-103
 Vitamin B₂, 103
 Vitamin C, 94, 105
 Vitamin D, 107, 221
 Vitamin E, 101
 Vitamin G, 95, 103
 Vitamin H, 96
 Vitamin K, 101
 Vitamin P-P, 104
 Vitamins, 92
 essential, 102
 Vitaphone, 239
 Vocoder, 249
 Voder, 249
 Vulcanite, 38, 67
 Vulcanization, 67
 of rubber, 60

W57A, 190
 Walnuts, chemurgic uses for, 82
 Warner Institute for Therapeutic Research, 109
 Water power, 267
 Waves, Hertzian, 168
 Weaver, W. L., 106
 Webb, B. H., 74
 Weidlein, Edward R., 143
 Weir, I. R., 192
 Wells, M. W., 222
 Wells, W. F., 222
 Westendorp, Willem F., 181
 Westinghouse Electric and Mfg. Co., 165, 187, 219, 222
 WGY, 189
 Science Forum, 247
 Whey, 74
 "Wheyfers," 74
 Whitby, L. E. H., 88
 Whitney, Willis R., 127, 212
 Whole-wheat flour, 101
 Wilder, Russell M., 100
 Williams, Greville, 62
 Williams, Robert R., 97, 102, 109
 Williams, Roger J., 7, 95
 Wilm, Alfred, 115
 Wimperis, H. E., 155
 Wind power, 272
 Wisansky, W. A., 110
 Wisconsin, University of, 95, 108, 221
 Wöhler, Friedrich, 113
 Wollaston, William H., 123
 Wood, John, 142
 Wood sugars, 78
 Wooley, D. W., 109
 WRGB, 205
 Wright Brothers, 155
 Wright, Gilbert M., 249
 Würzburg, University of, 168

X-rays, 169-170, 179-183
 X-ray tubes, multi-stage, 181

Yale University, 279
 Yarn, alkylation of, 57-58

Zein, 76
 Zeiss, Carl, 149
 Zworykin, V. K., 164, 184-186, 196

Concerning the Author

JAMES STOKLEY was born in Philadelphia on May 19, 1900. He pursued his undergraduate and graduate studies in biology and psychology at the University of Pennsylvania; and since 1925, following a period as a teacher in the Philadelphia Central High School, he has devoted himself to making available to a wider audience the specialized findings of scientific laboratories here and abroad. In 1931, after six years as staff writer with Science Service, Inc., in Washington, D.C., Mr. Stokley became associate director, in charge of astronomy, at the museum of the Franklin Institute in Philadelphia, where also he had charge of the photographic and seismographic sections. When the Institute's Fels Planetarium opened in 1933 he was its first director, continuing in his lectures there an interest which he had formed when studying the operation of the two original planetaria at Jena and Munich. His earlier book, *Stars and Telescopes*, gives a popular account of the studies of astronomers. His work in Philadelphia led to his appointment in 1939 as director of the Buhl Planetarium and Institute of Popular Science at Pittsburgh, and latterly as editor in physical sciences with Science Service, Inc. Since 1941 he has been associated with the General Electric Research Laboratory at Schenectady. In his preparation of **SCIENCE REMAKES OUR WORLD**, James Stokley has had access to many of the latest developments in the major university and industrial laboratories of the United States.

